OUTLINE OF AN ELEMENTARY COURSE

IN

PHYSICS

FOR

LEWIS INSTITUTE

BY

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PREFATORY NOTE.

These pages have been printed for the convenience of the students of Lewis Institute. As it is possible, however, that the book may fall into other hands, the following suggestions are offered:

The outline has grown from an effort made during the past year to build upon a fundamental knowledge of Algebra, Plane Geometry and Plane Trigonometry a substantial foundation for a study of applied mathematics.

Under the heading of lecture notes only topics and references are given, the idea being that the instructor is to present the subject as briefly or as fully as the conditions may warrant.

Even at the stage of the work contemplated here, it is assumed that a reference library, close at hand, is indispensible.

The right hand page of the outline has been left blank that the student may record such additional notes and exercises as the instructor may wish to give, and that the instructor may make such changes as his judgment may dictate and his laboratory demand.

A special form of Laboratory Note Book has been prepared and placed on sale at the Lewis Institute Book Store.

I wish to express my sense of obligation to my assistant, Mr. F. A. Rogers, for valuable services rendered in the preparation of the notes.

My colleague, Prof. C. W. Mann, has very kindly assisted, and the W. A. Olmsted Scientific Company and the Brown and Sharpe Manufacturing Company have kindly loaned cuts. We shall appreciate the favor conferred by any who call our attention to errors or offer suggestions.

C. W. C.

September 20, 1897.

DIRECTIONS TO STUDENTS.

There are many ways of studying Natural Philosophy or Physics. We may begin by committing to memory facts and laws, discovered by others, and by observing what is going on around us.

Another method, the one we shall follow, is to aid the method given above by means of daily work in the laboratory.

But do not think that going to the laboratory for a given length of time will bring about the desired end. This can be done only by following closely the directions given you, by careful thought on your part, much oral instruction and the assistance of many books.

The following general directions should be read carefully and kept in mind as a part of the special directions that are given you in the following pages:

RECITATION HOUR.—The recitation hour will be used: (1) to give you instruction regarding your work in the laboratory; (2) to question you on the work you have done previously; (3) to discuss the general principles of the subject, and (4) to sum up and review the previous work of the year.

THE LABORATORY.—It is very important that you remember the laboratory is designed for the accommodation and preservation of the apparatus to be used, as well as to serve the purpose of a place in which to use it. The utmost care must always be taken in moving and manipulating apparatus.

On entering the laboratory, take your place at the table assigned you. Read the directions given you as a guide in

performing the exercise for which the apparatus before you has been arranged. SKETCH THE APPARATUS USED. Record your MANIPULATIONS, OBSERVATIONS and CONCLUSIONS. When the work assigned you has been completed, you may spend in the REFERENCE ROOM the remainder of the time alloted.

Do not touch apparatus other than that designed for the work of the day. If a piece of apparatus is injured, inform your instructor at once. If you find you are unable to perform an exercise to your satisfaction, do not say to yourself (or to any one else), petulantly, "I can't," or "I do not understand it," but, after giving it CAREFUL THOUGHT, and having made EARNEST EFFORT, *ask* your instructor to assist you.

Your deportment in the laboratory must be unexceptionable. Talking or laughing, excess of any form of communication, anything ungentlemanly or unladylike, will render you liable to suspension from the laboratory and the class during the remainder of the year. The above, and more on this subject, may be summed up by saying that YOU KNOW how to conduct yourself, and that suspension will be based upon general, not upon specific directions.

NOTE-TAKING.—Make full notes while in the laboratory. Let neatness, accuracy and judgment be used in revising for your record-book. Let your work, sketches and records be your own. Nothing will lower you in the estimation of your classmates and instructor more than the practice of petty dishonesty.

REFERENCE ROOM.—Good instruction, both oral and written, are indispensable to rapid progress in your work. In the room adjoining the laboratory, you will find your

instructor (when not in the laboratory) and the reference books. Do not hesitate to consult either, when necessary. If you wish to take a book from the reference room, you may do so by following the directions given there.

The following is a list of some of the books of reference:

ELEMENTARY TEXT BOOKS.

Gage, Elements of Physics.
Avery, School Physics.
Carhart and Chute, Physics.
Nichols, The Outlines of Physics.
Appleton, School Physics.

ADVANCED TEXT BOOKS.

Carhart, University Physics.
Ames, Theory of Physics.
Daniell, Text Book of the Principles of Physics.
Anthony and Brackett, Text Book of Physics.
Barker, Physics.
Lord Kelvin and Tait, Elements of Natural Philosophy.

ELEMENTARY LABORATORY PRACTICE.

Chute, Practical Physics.
Stewart and Gee, Practical Physics for Schools.
Adams, Physical Laboratory Manual.
Trowbridge, The New Physics.
Hall and Bergen, A Text Book of Physics.
Austin and Thwing, Physical Measurement.
Stone, Experimental Physics.

ADVANCED LABORATORY PRACTICE.

Stewart and Gee, Elementary Practical Physics.
Nichols, A Laboratory Manual of Physics.
Pickering, Physical Manipulations.
Kohlrausch, Physical Measurements.

SPECIAL TOPICS.

MECHANICS.

Maxwell, Matter and Motion.
Loney, The Elements of Statics.
Loney, The Elements of Dynamics.
Goodeve, Principals of Mechanics.
Rankine, Applied Mechanics.
J. J. Thomson, Applications of Dynamics to Physics.
Smith, Graphics.

SOUND.

Tyndall, Sound.
Everett, Vibratory Motion and Sound.
Helmholtz, Sensations of Tone.
Airy, Sound.
Zahm, Sound and Music.
Blaserna, Sound and Music.

HEAT.

Stewart, Elementary Treatise on Heat.
Maxwell, Theory of Heat.
Tyndall, Heat a Mode of Motion.
Alexander, Thermo-Dynamics.
Day, Examples in Heat.

Thurston, The Stationary Steam Engine.
Sennett, Marine Steam Engine.

METEOROLOGY.

Buchan, Elementary Meteorology.
Davis, Elementary Meteorology.
Greeley, American Weather.
Russell, Meteorology.
Scott, Elementary Meteorology.
Weather Bureau Reports.
Weather Maps.

LIGHT.

Woodhull, First Course in Science.
Dolbear, The Art of Projecting.
Tyndall, On Light.
Vogel, Chemistry of Light and Photography.
Aldis, Elementary Geometrical Optics.
Wright, Light.
Spottiswood, Polarization of Light.
Lommel, Nature of Light.
Tait, Light.
Preston, Theory of Light.

ELECTRICITY AND MAGNETISM.

Barnard, First Steps in Electricity.
Thompson, S. P., Elementary Lessons in Electricity and Magnetism.
Carhart, Primary Batteries.
Larden, Electricity.
Ayrton, Practical Electricity.

Stewart and Gee, Elementary Practical Physics, Vol. II.
Carhart and Patterson, Electrical Measurements.
Thompson, S. P., Dynamo-Electric Machinery.
Maxwell, Electricity and Magnetism.
Faraday, Researches.
Flemming, Alternate-Current Transformer.
Ewing, Magnetic Induction in Iron.
Bedelland Crehore, Alternating Currents.
Thompson, S. P., The Electromagnet.
Cavandish, Electric Researches.
Hertz, Electric Waves.
Thompson, J. J., Researches.
Prescott, Electricity and Electric Telegraph.
Maver, American Telegraph.
Palaz-(Patterson), Industrial Photometry.
Martin and Wetzler, The Electric Motor.
Houston and Kennelly [10 Vols.], Electro Technical Series.
Slingo and Brooker, Electrical Engineering.
Kempe, Handbook of Electrical Testing.
Martin [Tesla's Writings].
Hering, Electricity at Paris Exposition.
Crosby and Bell, The Electric Railway.
Crocker-Wheeler, Management of Dynamos and Motors.
Gore, Electrolytic Deposition of Metals.
Fontaine, Electrolysis.
Dodge, Modern Views of Electricity.
Plante, Storage of Electrical Energy.

POPULAR PHYSICS.

Routledge, A Popular History of Science.
Faraday, On the Various Forms of Nature.

... of Electricity.

... Faraday.

... Lectures to Electric Artisans.

PERIODICALS.

... American.

... Electrician.

... Engineer (New York).

... Engineer (London).

... World.

... (London).

... Electrique.

... Electrique.

... Zeitschrift.

ABBREVIATED REFERENCES.

... Students.

... of Physics.

... A Laboratory Manual of

... Elements of Physics.

Helmholtz, Popular Science Lectures.
Lodge, Pioneers of Science.
Dolbear, Telephone.
Galton, English Men of Science.
Mendenhall, A Century of Electricity.
Tyndall, Michael Faraday.
Fleming, Short Lectures to Electric Artisans.

PERIODICALS.

Scientific American.
Western Electrician.
Electricity.
Electrical Engineering (New York).
Electrical Engineering (London).
Electrical World.
Electrician (London).
L'Eclairage Electrique.
L'Electricien.
L'Industrie Electrique.
Electrotechnische Zeitschrift.

ABBREVIATED REFERENCES.

Carhart, Physics for University Students.
Ames, The Theory of Physics.
Nichols' Outlines, The Outlines of Physics.
Nichols' Laboratory Manual, A Laboratory Manual of Physics and Applied Electricity.
Gage, The Principles of Physics.
Avery, School Physics.
C. and C. Carhart and Chute, Elements of Physics.

STANDARD UNITS.

Conditions determining a standard unit of measurement:

(a). It must be a definite thing—kind of matter.

(b). It must be a definite quantity of that thing.

(c). It must be authorized by an act of the government for which it is a standard.

The imperial standard yard is the standard unit of length for British government.

By an act of Parliament, it is the distance between the intersections of the transverse lines in the two gold plugs in a bronze bar deposited at the office of the Exchequer in London, the temperature of the bar being 62° F.

The standard yard for the United States is a copy from the British unit, and is very nearly equal to it.

The metre is the standard unit of length for the French government.

By an Act of the Government it is the distance between the ends of a certain platinum bar preserved in the Archives de l'Etat in Paris, the bar being at the temperature of melting ice.

The metre was intended to be exactly one ten-millionth part of a quadrant of the earth's meridian passing through Paris, but it is a trifle in error.

TABLE

Of Relative Values of English and Metric Measures.

English in Metric.	Value.	Metric in English.	Value.
1 English inch in centimetres	2.5399772	1 centimetre in English inches	0.39370421
1 English foot in metres....	0.30479727	1 metre in English feet.......	3.28086933
1 English yard in metres....	0.91439180	1 metre in English yards.....	1.09362311
1 English statute mile in kilometre......	1.6093295	1 kilometre in English statute miles...............	0.61237677
1 square foot in centiares...	0.09280137	1 centiare in square feet......	10.764104
1 acre in hectares...........	0.4046783	1 hectare in acres............	2.4710982
1 square mile in hectares....	258.99416	1 hectare in square miles.....	0.00386109
1 cubic foot in cubic metre (steres)...............	0.02831608	1 cubic metre in cubic feet....	35.315617
1 cord in steres.............	3.6244589	1 stere in cords..............	0.2759033
1 Imperial gallon in litres...	4.5435845	1 litre in Imperial gallons....	0.2200906
1 U. S. gallon in litres.......	3.785	1 litre in U. S. gallons........	0.264
1 U. S. bushel in litres......	35.24	1 litre in U. S. bushels........	0.02338
1 Imperial quart in litres....	1.1358961	1 litre in Imperial quarts.....	0.8803624
1 U. S. liquid quart in litres.	0.94625	1 litre in U. S. liquid quarts..	1.056
1 U. S. dry quart in litres....	1.10125	1 litre in U. S. dry quarts.....	0.90816
1 grain in grams............	0.0647989	1 gram in grains..............	15.4324874
1 pound (Avor.) in kilograms	0.54359265	1 kilogram in pounds (Avoir)	2.20462125
1 pound (Troy) in kilograms	0.37324196	1 kilogram in pounds (Troy).	2.67922721
1 foot pound (Avor.) in kilometres...............	0.1382538	1 kilogram metre in foot pounds (Avoir).........	7.2330743

MATHEMATICAL DATA AND FORMULAS.

π (ratio of circumference of circle to diameter) $= 3.14159$
Circumference of a circle (radius r) $= 2 \pi r$
Area of circle (radius r) $= \pi r^2$
Surface of a sphere (radius r) $= 4 \pi r^2$
Surface of an ellipse (semi-axes a and b) $= \pi a b$
Surface of right cylinder (height h, base πr^2) $= 2 \pi r h + 2 \pi r^2$
Surface of right cone (height h, base πr^2) $= \pi r^2 + 2 \pi r \frac{1}{2} s l$
Volume of a sphere (radius r) $= \frac{4}{3} \pi r^3$
Volume of ellipsoid (semi-axes, a, b and c) $= \frac{4}{3} \pi a b c$
Volume of right cylinder (height h, base πr^2 $= \pi r^2 h$
Volume of right cone (height h, base πr^2) $= \frac{1}{3} \pi r^2 h$
Sum of three angles of a triangle $= 180°$
Area of a triangle of altitude h, base b $= \frac{1}{2} b h$

Two triangles which have equal bases and equal altitudes are equal.

ANGLE.	ARC.	SINE.	COS.	TAN.	COT.	SEC.	COSEC.
0°	0	0	1	0	∞	1	∞
30°	$\frac{1}{6}\pi$	$\frac{1}{2}$	$\frac{1}{2}\sqrt{3}$	$\frac{1}{3}\sqrt{3}$	$\sqrt{3}$	$\frac{2}{3}\sqrt{3}$	2
45°	$\frac{1}{4}\pi$	$\frac{1}{2}\sqrt{2}$	$\frac{1}{2}\sqrt{2}$	1	1	$\sqrt{2}$	$\sqrt{2}$
60°	$\frac{1}{3}\pi$	$\frac{1}{2}\sqrt{3}$	$\frac{1}{2}$	$\sqrt{3}$	$\frac{1}{3}\sqrt{\ }$	2	$\frac{2}{3}\sqrt{3}$
90°	$\frac{1}{2}\pi$	1	0	∞	0	∞	1
120°	$\frac{2}{3}\pi$	$\frac{1}{2}\sqrt{3}$	$-\frac{1}{2}$	$-\sqrt{3}$	$-\frac{1}{3}\sqrt{3}$	-2	$\frac{2}{3}\sqrt{3}$
135°	$\frac{3}{4}\pi$	$\frac{1}{2}\sqrt{2}$	$-\frac{1}{2}\sqrt{2}$	-1	-1	$-\sqrt{2}$	$\sqrt{2}$
150°	$\frac{5}{6}\pi$	$\frac{1}{2}$	$-\frac{1}{2}\sqrt{3}$	$-\frac{1}{3}\sqrt{3}$	$-\sqrt{3}$	$-\frac{2}{3}\sqrt{3}$	2

DIMENSIONS OF DYNAMICAL UNITS.

T denoting a time, L a length, M a Mass.

	Velocity	Acceleration	Momentum	Force	Energy
DIMENSION........	$\frac{L}{T}$	$\frac{L}{T^2}$	$\frac{ML}{T}$	$\frac{ML}{T^2}$	$\frac{ML^2}{T^2}$

Mass × velocity = mass × acceleration × time = force × time.

ALPHABETICAL TABLE

Of Equivalent Values of Weights and Measures.

1 Ar = 100 sq. metres, 119.6 sq. yds.

1 Centar = 1 sq. metre = 10,000 sq. centimetres, 1,550 sq. in.

1 Centimetre = 1-100 of a metre, .3937 inches.

1 cubic centimetre (of distilled water) = 1 gram, .0610 cubic inches.

1 cubic decimetre (same as 1 litre) 1000 [c m^3]

1 cubic decimetre of distilled water, weighs 1000 grams, 1 kilogram.

1 cubic decimetre in English or Imperial measure, .8804 qts.

1 cubic decimetre in American or wine measure, 1.0567 quarts.

1 cubic foot (1728 cubic inches) 28,315.319 [c m^3].

1 cubic foot of water (at 62° F.) weighs 62.3210 lbs. av.

1 cubic inch, 16.3861 [c m^3].

1 cubic inch of water (at 60° F.) weighs 252.5 grains.

1 cubic inch of water (at 62° F.) weighs 252.458 grains.

1 cubic metre (1 ster) = 1,000,000 c. c. or 1,000 litres.

1 fluid oz. imperial = 28.4 c. c. 1.7329 cu. inches.

1 fluid oz. wine measure = 29.5 c. c. 1.8047 cu. inches.

1 fluid oz. imperial of water (62° F.) 437.5 grains.

1 fluid oz. wine measure of water (60° F) weighs 456.0 grains.

1 foot, 30.48 centimetres.

1 gallon imperial=277.274 cu. inches 4.7852 litres.

1 gallon imperial of water weighs (62° F.) 10 lbs. or 70,000 grains.

1 gallon wine measure=231 cu. inches, 3.7852 litres.

1 gallon wine measure of water weighs (60° F.) 8.34 lbs. =58,372.2 grs.

1 gram (weight of 1 c. c. of dist. water 4° C.) 15.4323 grains.

1 inch 2.54 centimetres.

1 kilogram (1,000 grains) 2.2046 lbs. avoir.

1 litre (see cubic decimetre.)

1 metre ($\frac{1}{40000000}$ of earth's meridian) 3 ft. 3⅜ in.; 39.3708 inches.

1 pint, wine measure=16 fluid oz.=of water (60° F.) 7296.5 gr.=473.148 [c m³].

1 pint imperial=20 fluid oz.=of water (62° F.) 8,750 gr. =567.932 [c m³].

1 quart wine measure=32 fluid oz. .9463 litres.

1 quart, imperial=40 fluid oz., 1.1358 litres.

1 ton avoirdupois (2,000 lbs.) 29166⅔ oz. Troy.

1 tonneau 1,000,000 grams 1,000 kilos.

THE C. G. S. SYSTEM OF UNITS.

The C. G. S. System of Units is the result of an attempt to express all quantities with which physical science deals in terms of three fundamental units :—

A Unit of Length—The centimetre.

A Unit of Mass—The gram.

A Unit of Time—The second.

From these the following units are derived :—

Unit of Surface—The square centimetre.

Unit of Volume--The cubic centimetre.

Unit of Velocity—The velocity of one centimetre per second.

Unit of Acceleration—The acceleration which imparts unit velocity to a body in one second.

Unit of Force—The dyne; the force which, acting on a gram mass for one second, imparts to it a unit of velocity.

Unit of Work—The erg; the work done by a dyne, working through one centimtre.

Unit of Energy—Also the erg; since the energy of a body is measured by the amount of work it can do.

Unit of Heat—The amount of heat required to raise one gram of water from 0° to 1° C.

Unit Magnetic Pole.—A magnetic pole has unit strength when it repels a similar pole of equal strength, one centimetre distant in air, with the force of a dyne.

Unit of Electric Current (electro-magnetic system)—A current of such strength that one centimetre of its circuit, bent so that every point of it is one centimetre distant from a unit magnetic pole, exerts upon this pole the force of a dyne.

Unit of Electric Quantity (electro-magnetic system)—The quantity conveyed by a unit current in one second.

Unit of Difference of Potential (electro-magnetic system)—Two points have unit difference of potential when one erg of work must be expended to bring a unit of + electricity from one to the other against the electric force.

Unit of Electric Resistance (electro-magnetic system)—A conductor possesses unit resistance when a unit difference of potential between its ends causes a unit current to flow through it.

ALPHABETICAL TABLE OF UNITS USED IN PHYSICAL SCIENCE.

Ampere.—Unit of electric current; 10^{-1} C. G. S. units; it is practically represented by the current which will deposit silver from silver nitrate at the rate of 0.001118 gm. per second.

Calorie.—Unit of heat; it is the heat required to raise one gram of water one degree.

Cheval-de-vapeur. See Force-de-cheval.

Coulomb.—Unit of electric quantity; 10^{-1} C. G. S. units; it is the quantity conveyed by a current of one ampere in one second.

Current.—See Ampere.

Dyne.—Unit of force; it is that force which, acting on a mass of one gram for one second, gives to it a velocity of one centimetre per second.

Erg.—Unit of work; it is the work done by one dyne through a distance of one centimetre.

Electromotive force.—See Volt.

Farad.—Unit of electric capacity; 10^{-9} C. G. S. units; it is the capacity of a condenser which is charged to a potential of one volt by one coulomb. The microfarad, chiefly used in practice, is one-millionth of a farad, or 10^{-15} C. G. S. units.

Foot-pound.—English unit of work; work required to raise one pound through one foot in opposition to the force of gravity.

Force.—See Dyne.

Force-de-cheval.—French unit of power; .9864 horse-power; power of doing 75 kilogram-metres (542.5 foot-pounds of work per second.)

Gram.—Unit of mass.

Heat.—English unit of; heat required to raise one pound of water from 32° to 33° F.

Horse-power.—English unit of power; power required to perform 550 foot pounds of work per second.

Henry.—Unit of induction; 10^9 C. G. S. units; it is the induction in a circuit when the electromotive force induced in this circuit is one volt, while the inducing current varies at the rate of one ampere per second.

Kilogrammetre.—French unit of work; work required to raise one kilogram of mass through one metre in opposition to force of gravity.

Mass.—Units of. See Gram and Pound.

Ohm.—Unit of electric resistance; 10^9 C. G. S. units; it is the resistance of a uniform column of mercury 106.3 centimeters in length and 14.4521 gms. mass at 0° C.

Potential—Unit difference of. See Volt.

Pound.—English unit of mass; regarded as a weight it is also used as the unit of force, i. e., the force exercised by the mass of a pound (where $g = 981$: London).

Power.—Unit of. See Force-de-cheval, Horse-power, and Watt.

Quantity.—Unit of electric. See Coulomb.

Resistance.—Unit of electric. See Ohm.

Volt.—Unit of electromotive force; 10^8 C. G. S. units; it is $\frac{1000}{1434}$ of the E. M. F. of a standard Clark cell at 15° C.

Watt.—Unit of ~~electric~~ power; it is 10^7 ergs per second.

Weber.—Unit of magnetic flux.

Work.—See Foot-pound, Kilogrammetre, and Erg.

DENSITIES OF SUBSTANCES IN GRAMS PER CUBIC CENTIMETRES.

Agate	2.615
Alcohol (absolute)	0.806
Alcohol (common)	0.833
Aluminum	2.670
Antimony (cast)	6.720
Appletree wood	0.790
Ash, dry	0.690
Ash, green	0.760
Asphalt	2.500
Beech, dry	0.690 to 0.800
Beeswax	0.964
Bell-metal	8.050
Benzine	0.72 to 0.740
Birch	0.690
Bismuth (cast)	9.822
Boxwood	1.280
Brass, cast	8.400
Brass, sheet	8.440
Brick,	1.6 to 2.000
Coal, anthracite	1.26 to 1.800
Coal, bitum.	1.270 to 1.423
Cork	0.240
Cedar, American	0.554
Chalk	1.8 to 2.800
Cherry	0.710
Chestnut	0.606
Copper, cast	8.830
Copper, sheet	8.878
Diamond	3.530
Ebony	1.187
Elm	0.579
Elm, Canadian	0.725
Emery	3.900
Ether	0.736
Fir, spruce	0.512
Fluor-spar	3.200
Galena	7.580
German-silver	8.432
Glass, flint	3.000 to 3.600
Glass, crown	2.520
Glass, plate	2.760
Glycerine	1.260

Gold	19.360
Gypsum, crys	2.310
Granite	2.650
Graphite	2.500
Gun, metal	8.561
Hydrochloric acid	1.222
Ice	0.917
Iron, bar	7.788
Iron, cast	7.230
Iron, wrought	7.780
Iron pyrites	5.000
Ivory	1.820
Lead, cast	11.360
Lead, sheet	11.400
Lignum vitæ	1.333
Limestone	3.180
Mahogany	0.56 to 0.852
Maple	0.755
Marble	2.720
Mercury	13.596
Naphtha	0.848
Nitric acid	1.35 to 1.559
Oak, American, red	0.850
Oak, American, white	0.779
Oak, live, seasoned	1.068
Oil, turpentine	0.870
Paraffine	0.824 to 0.940
Petroleum	0.836
Phosphorus	1.830
Pine, white, dry	0.554
Pine, Norway	0.689
Pine, yellow, dry	0.461
Pine, pitch	0.660
Platinum, wire	21.531
Porcelain, china	2.380
Quartz	2.650
Saltpeter	2.100
Sand, quartz	2.750
Silver, cast	10.424 to 10.511
Slate	2.880
Steel, unhammered	7.816
Sulphur, native	2.033
Sulphuric acid	1.840
Tallow	0.940
Tin, cast	7.290
Walnut	0.680
Water, sea	1.027
Wax, white	0.970
Zinc, cast	7.000

—*Adams.*

Specific Gravity of Aqueous Solutions at 15° C. The % signifies the weight of the substance (salts are anhydrous) to 100 parts by weight of the solution.

%	Na Cl	Cu S O_4	Zn S O_4	Ag N O_3	H_2 S O_4	Alcohol.
5	1.035	1.050	1.052	1.043	1.0334	0.9904
10	1.072	1.103	1.108	1.090	1.0687	0.9831
15	1.110	1.161	1.168	1.141	1.1048	0.9769
20	1.150	(1.225)	1.236	1.197	1.1430	0.9708
25	1.191		1.307	1.257	1.1816	0.9644
30			1.382	1.323	1.2230	0.9565
35				1.396	1.264	0.9485
40				1.479	1.307	0.9390
45				1.572	1.352	0.9287
50				1.677	1.399	0.9179

—*Adams.*

COEFFICIENTS OF LINEAR EXPANSION.

Aluminum 0.00002221	Lead............0.00002798
Brass............0.00001875	Silver 0.00001943
Copper 0.0000017	Steel, tempered..0.00001322
Iron, cast 0.00001125	Steel, untempered.0.00001095
Iron, wrought...0.00001220	Zinc............0.00002976

SPECIFIC HEATS.

Aluminum...........0.2122	Lead 0.0315
Brass................0.086	Mercury 0.0335
Copper 0.0933	Nickel..............0.1092
Ice 0.504	Silver 0.0559
Iron.................0.1124	Zinc.................0.0935
Glass 0.1770	

—*Adams.*

NOTE.—The Greek alphabet is in such common use for the expression of values in applied mathematics that it is deemed desirbale to append the following statement for the benefit of the student not familiar with Greek:

THE ALPHABET AND PRONUNCIATION.

1. The Greek alphabet consists of twenty-four letters :—

Form.	*Equivalent.*	*Value.*	*Greek Name.*	*Pronunciation.*
Α α	*a*	comm*a*, f*a*ther	ἄλφα	alpha
Β β	*b*	*b*ox	βῆτα	beta (*bāta*)
Γ γ	*g*	*g*o, a*n*kle	γάμμα	gamma
Δ δ	*d*	*d*o	δέλτα	delta
Ε ε	*ĕ*	pen	ἒ ψιλόν	epsilon (*ĕ-pseelŏn*)
Ζ ζ	*z*	ad*z*e	ζῆτα	zeta (*dzāta*)
Η η	*ē*	they	ἦτα	eta (*āta*)
Θ θ ϑ	*th*	*th*in	θῆτα	theta (*thāta*)
Ι ι	*i*	k*i*n, mach*i*ne	ἰῶτα	iota (*eōta*)
Κ κ	*k* (hard *c*)	*k*ill	κάππα	kappa
Λ λ	*l*	*l*ip	λάμβδα	lambda
Μ μ	*m*	*man*	μῦ	mu (*mü*)
Ν ν	*n*	*no*	νῦ	nu (*nü*)
Ξ ξ	*x*	bo*x*	ξῖ	xi (*ksee*)
Ο ο	*ŏ*	*o*bey	ὂ μῖκρόν	omicron (*ŏ-meecrŏn*)
Π π	*p*	*p*it	πῖ	pi (*pee*)
Ρ ρ	*r*	*hr*	ῥῶ	rho
Σ σ ς[4]	*s*	*s*o	σίγμα	sigma
Τ τ	*t*	*t*in	ταῦ	tau (rhymes with *now*)
Υ υ	*u* or *y*	Ger. Lücke, kühl	ὖ ψιλόν	upsilon (*ū-pseelŏn*)
Φ φ	*ph*	*ph*ase	φῖ	phi (*phee*)
Χ χ	*ch*	Ger. a*ch*t	χῖ	chi (*chee* [hard *ch*])
Ψ ψ	*ps*	li*ps*	ψῖ	psi (*psee*)
Ω ω	*ō*	tone	ὦ μέγα	omega (*ō-mĕga*)

LECTURE NOTES.

I.

PHYSICS:

Etymology of the term.

Formerly, embraced the phenomena of nature.

Now, restricted to energy associated with matter.

PHYSICS AS RELATED TO:

Biological science.

Geological science.

Astronomical science.

Chemical science.

TERMS DISCUSSED:

Mental Philosophy, Metaphysics; Natural Philosophy, Physics.

Deductive and Inductive methods.

Psychology and the psychological laboratory. The methods of the study of physics now used.

METHOD AND AIM:

To determine the *casual* relation between phenomena.

Constancy of the *Order* of *Nature*.

Theory.

Experiment.

Rise of the Laboratory.

- Qualitative work.
- Quantitative work.

Measurements.

- Expressing results numerically.

FUNDAMENTAL:

Matter	Time	Space
Mass	Time	Length
Gram	Second	Centimetre
Centimetre	Gram	Second [C–G–S]

GENERAL SUBDIVISION:

Physics of Matter.
Physics of Ether.

PHYSICS OF MATTER:

(Molar and Molecular Physics.)
Mechanics.
Sound.
Heat.

MECHANICS:

Introduction.
Properties of matter.
Kinematics.
Dynamics:
  Statics.
  Kinetics.

SOUND.

HEAT.

PHYSICS OF ETHER:

(Ether Physics.)

"RADIANT HEAT."

LIGHT.

MAGNETISM AND ELECTRICITY.

PHYSICS OF MATTER:

- Mechanics.
- Introduction.
  - Structure of Matter.
  - Divisions.
    - Mass.
    - Molecule.
    - Atom.
  - Solids.
  - Fluids:
    - Liquids.
    - Gases.
- Experimentation.
- Standards of measurements.
- Systems of measurements.

EXPERIMENTS ILLUSTRATING THE:

General *Properties of Matter.*	Specific *Properties of Matter.*
Extension.	Hardness.
Impenetrability.	Tenacity.
Mass	Malleability.
Weight.	Ductility.
Indestructibility.	Crystallization.
Inertia.	Surface Films.
Porosity.	Surface Tension.
Strain.	Viscosity.
Stress.	Capillarity.
Elasticity.	Absorption.
Cohesion.	Diffusion.
Adhesion.	Osmose.

References:

Carhart, Arts. 1-8.
Ames, Arts. 1-9.
Nichols Outlines, Arts. 1-9.
Gage, Arts. 1-8.
Avery, Arts. 1-52.
C. & C., Arts. 1-39.
Tait, Chs. I-VI.
Maxwell, Matter and Motion, Ch. I.
Thomson & Tait, Elements of Natural Philosophy, Ch. IV.
Dolbear, Matter, Ether and Motion, Ch. I.
Routledge, A Popular History of Science.

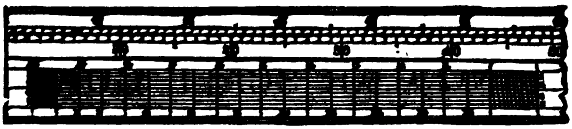
LABORATORY.

Mechanics.

REFERENCES:

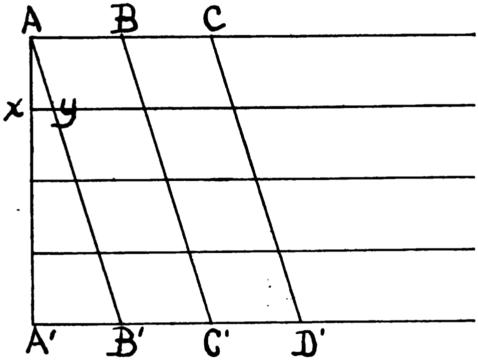
Stewart & Gee, Exercise 5.
Nichols, Laboratory Manual, Introduction.
Everett, C. G. S. System of Units, Chs. I and II.
Austin and Thwing, Phys. Meas. Introduction.
Chute, Exercise 2.

The Diagonal Scale. The following is the general theory:



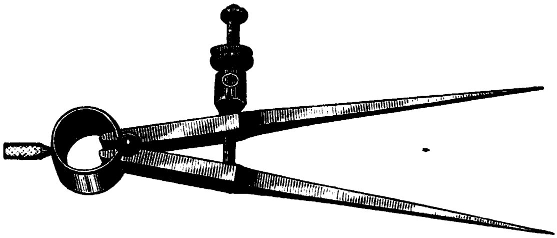
Let L = the distance between two consecutive diagonal lines, n the number of parallel longitudinal lines, and c the "least

count." In the figure, L = AB = BC = A′B′ and c = xy. Then Ax = 1/n AA′ and Ay = 1/n A B′ ∴ xy



= 1/n A′B′ since △s Axy and A A′B′ are similar. But xy = c = "least count" and A′B′ = L. ∴ c = 1/n L.

Exercise 1 (a). By means of the dividers and diagonal scale, determine as nearly as possible the distance between



the points on the brass plate furnished you, using both English and metric systems. Repeat three times and tabulate results. Reduce the results obtained in each system to the

corresponding values in the other. Give reasons for the differences, if any, between the measured and derived values.

Compare values obtained in the laboratory with those in reference tables, wherever possible, and record the differences.

(b) On the opposite side of the plate previously measured will be found a triangle. Measure the length of the sides, including the marked angle, and compute the third side and the area.

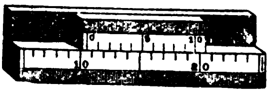
(c) Determine the least count of the verniers on the barometer.

THE VERNIER.

REFERENCES:

Stewart & Gee, Exercises 7–11.
Austin & Thwing, Pt. I. to Exercise 3.
Chute, Exercises 6–9.

The General Theory of the Vernier. It will be seen that by making *n* divisions of the Vernier equal to n–1 or n + 1 divisions of the sale, measurements may be obtained



to the 1/n of a scale division; for let L denote the length of a scale division, and V the length of a Vernier division, then first,

$$L(n-1) = Vn$$
$$\text{or } Vn = L(n-1)$$
$$\text{Then } Vn = Ln - L$$

Dividing by n, $V = L - L/n$

Transposing and dividing by -1

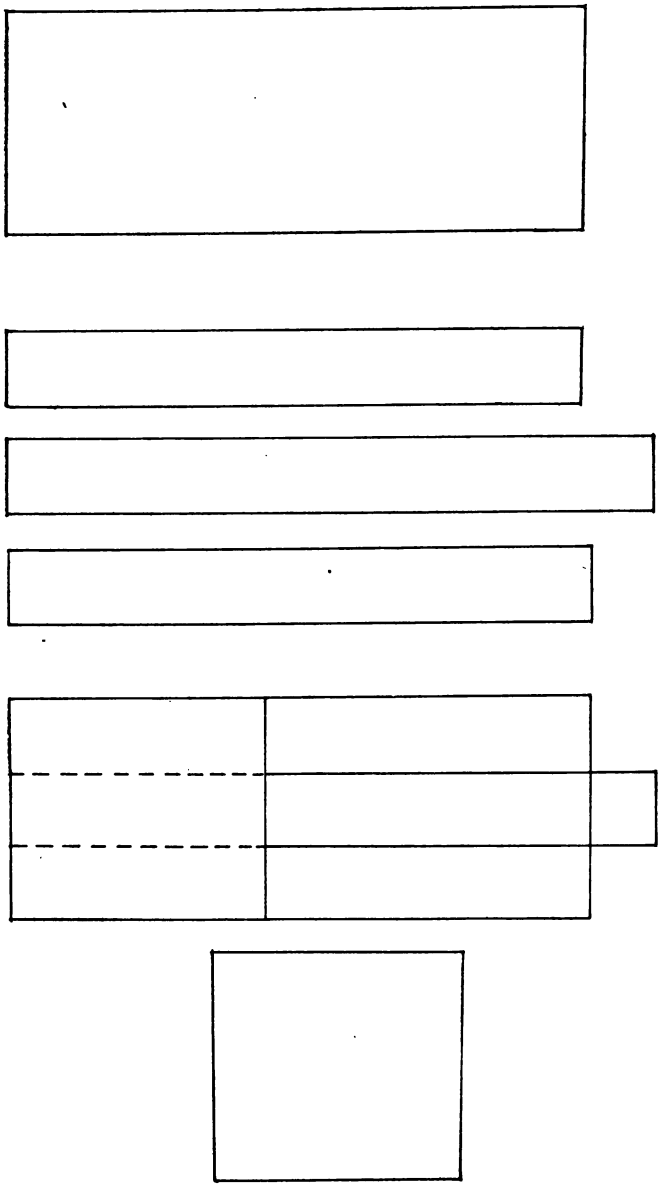
$$L - V = L/n = 1/n\ L$$
$$\text{or again } L(n+1) = Vn$$
$$\text{or } Vn = L(n+1)$$
$$\text{Then } Vn = Ln + L$$

Dividing by n, $V = L + L/n$

Transposing, $V - L = L/n = 1/n\ L$

In the latter case the Vernier reads backwards; but the difference between the divisions is more evident. The quantity $1/n\ L$ is called the "least count" of the Vernier.

(Modified from Stewart & Gee, Elementary Practical Physics.)

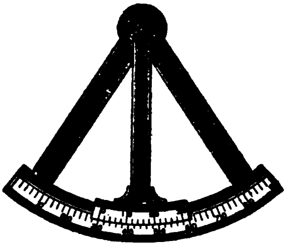


CARDBOARD MATERIAL FOR STRAIGHT VERNIER.

Exercise 2 (a). Construct a straight vernier from the material furnished you.

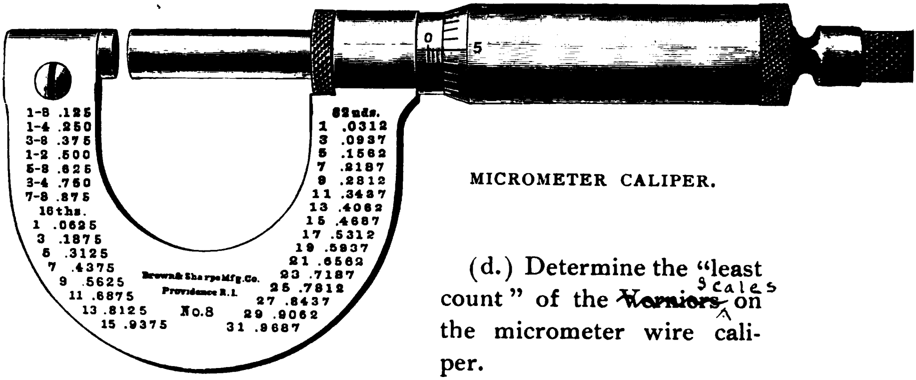
Calibrate in both English and metric systems from ratios assigned you. Determine the least count in each case.

(b.) Construct a circular vernier from the material furnished you. Calibrate so as to make the least count one degree of arc.



CIRCULAR VERNIER.

(c.) Determine the "least count" of the Vernier on the torsion apparatus.

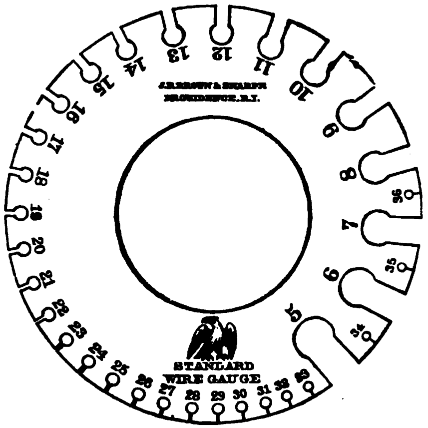


MICROMETER CALIPER.

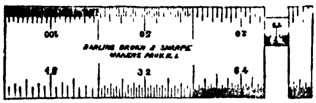
(d.) Determine the "least count" of the ~~Verniers~~ scales on the micrometer wire caliper.

Measurement of Diameters.

Exercise 3 (a). By means of the Wire Gauge, select the following numbers from the wires furnished you: 20, 18, 16, 14, 12, 10, 8, 6, 4, 3, 2, 1, 0.

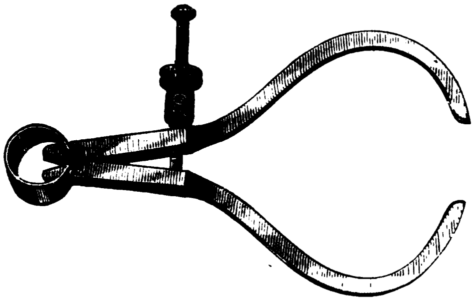


(b.) Determine their diameters by means of the English and metric micrometer caliper and check your results with the caliper rule. Tabulate results.



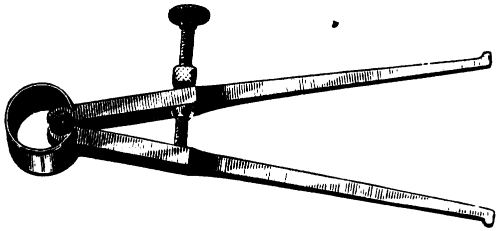
CALIPER RULE.

(c.) By means of the outside caliper determine the diameter of three or more of the brass rods furnished you, using both the English and metric systems.



OUTSIDE CALIPERS.

(d.) By means of the inside calipers, determine the bore of three or more of the brass tubes furnished you, using both English and metric systems.



INSIDE CALIPERS.

(e.) By means of the outside calipers, dividers and rule, or by means of the caliper rule, determine the area and volume of one of the brass plates furnished you, using both English and metric systems.

(f.) With the circular brass plate furnished you make similar measurements and computations as in (e) above.

REFERENCES:

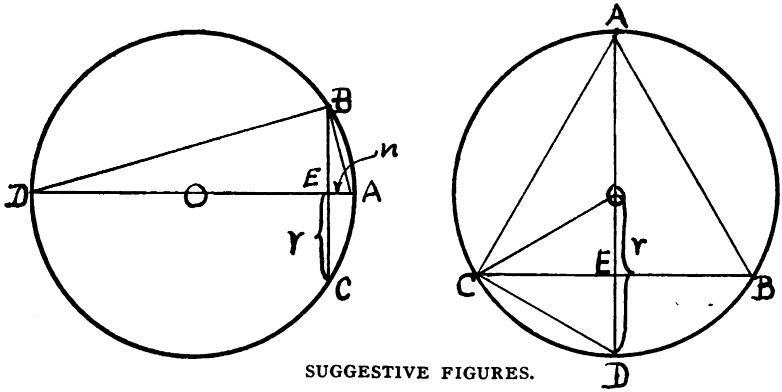
Stewart & Gee, Exercise 12.
Austin & Thwing, Exercises 3-6.
Nichols, Laboratory Manual, Ch. I., Exp. A-1.
Pickering, Art. 14.
Chute, Exercise 11.

THE SPHEREOMETER.

Exercise 4 (a). Determine the thickness of the "microscopic object covering glass" furnished you, using both the English and metric micrometer caliper and the sphereometer. Tabulate the results and differences.

SPHEREOMETER.

(b.) Determine by means of the sphereometer the radius of curvature of the convex and concave lenses, and convex and concave mirrors, furnished you. Tabulate your results. Make a diagram and give your method in full.



SUGGESTIVE FIGURES.

LECTURE NOTES.

II.

Plane Loci.

(Curve Tracing.)

(Olney's General Geometry and Calculus.)

1. The term *Locus* as used in geometry is nearly synonymous with *geometrical figure*, yet having a latitude in its use which the latter term does not possess. The locus of a point is the line (geometrical figure) generated by the motion of the point according to some given law. In the same manner a surface is conceived as the locus of a line moving in some determinate manner.

2. A device by means of which we are enabled to represent loci by means of equations is called a

METHOD OF CO-ORDINATES.

3 There are two systems of co-ordinates in common use, viz:

1. The system of Rectilinear Co-ordinates.
2. The system of Polar Co-ordinates.

4. There are two varieties of the rectilinear system of co-ordinates, the *rectangular* and the *oblique*. (In our study, the rectangular system will always be used unless otherwise specified.)

5. In order to locate a point in a plane by the method of rectangular co-ordinates, two lines intersecting each other are assumed as fixed in position. These lines are called *Axes of Reference*, or, simply, *The Axes*. The system is called rectangular or oblique, according as these lines make right or oblique angles, with each other.

6. One of these axes is called the *Axis of Abscissas*, and the other is called the *Axis of Ordinates.*

7. *The Origin* is the intersection of the axes.

8. *The Co-ordinates* of a point are its distances from the axes, the distance to either axis being measured on a line parallel to the other, or on that other axis.

9. *The Abscissa* of a point is the co-ordinate which is measured parallel to or on the axis of abscissas, and is the distance of the point from the axis of ordinates measured on a line parallel to the axis of abscissas.

10. *The Ordinate* of a point is the co-ordinate which is measured parallel to or on the axis of ordinates, and is the distance of the point from the axis of abscissas measured on a line parallel to the axis of ordinates.

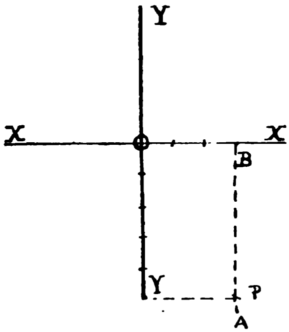
11. *A constant* quantity is one which maintains the same value throughout the same discussion, and is represented in the notation by one of the leading letters of the alphabet.

12. *Variable* quantities are such as may assume in the same discussion any value, within certain limits determined by the nature of the problem, and are represented by the final letters of the alphabet.

13. *Problem.* To locate a point whose co-ordinates are given.

Solution: Lay off from the origin, on the axis of abscissas, a distance equal to the given abscissa, to the right

if the abscissa is +, and to the left if it is—. Through the point thus formed draw a line parallel to the axis of ordinates, and lay off on it a distance from the axis of abscissas equal to the given ordinate, above if the ordinate is +, and below if it is —. The point thus found will be the one required.



Ex. 1. Locate the point $x=3$, $y=-5$. Draw the axes XX′ and YY′. Lay off OB=3 to the right as x is +, and draw BA parallel to the axis YY′ Then take BP=5 below the axis of abscissas as y is—, and P is the point required.

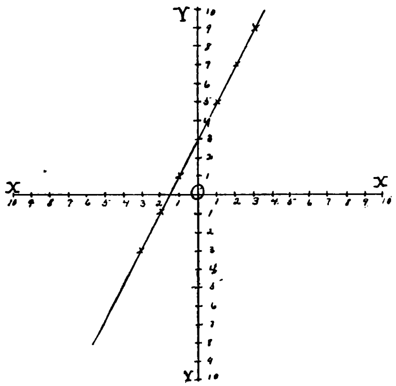
14. Problem. To find the locus of an equation between two variables; i. e., to construct the equation.

15. Ex. 1. Construct the equation $\frac{y-2x}{3}=1$.

Solution. Solving the equation for y, we have $y=2x+3$. Now, attributing arbitrary values to x, we have the following table of corresponding values:

When $x=0$, $y=3$.
" $x=1$ $y=5$, giving the point 1, 5;
" $x=2$ $y=7$ " " " 2, 7;
" $x=3$, $y=9$, " " " 3, 9;
" $x=-1$, $y=1$, " " " −1, 1;
" $x=-2$, $y=-1$, " " " −2, −1;
" $x=-3$, $y=-3$, " " " −3, −3;
etc., etc.

Noticing that all positive values of x give *real*, *positive*, and single values to y, we discover that the locus has but one branch which extends to the right of the axis of ordinates, extends indefinitely, and lies above the axis of abscissas.



Again, giving negative values to x, we have

When $x=-1$, $y=\ 1$, giving the point $-1,\ 1$;

" $x=-2$, $y=-1$, " " " $-2.\ -1$;

" $x=-3$, $y=-3$, " " " $-3, -3$;

and for all subsequent negative values of x, y has *real*, *negative*, and *single* values, hence we learn that the locus has a single branch extending indefinitely in the third angle.

If we make $y=0$, $x=-1\frac{1}{2}$; whence we see that the locus cuts the axis of abscissas at $-1\frac{1}{2}$, 0. If we make $x=0$, $y=3$; and hence the locus cuts the axis of ordinates at 0, 3.

19. *The Independent Variable* is the one to which we assign arbitrary values, usually x. The other is called the *Dependent Variable.*

This distinction is made simply for convenience, and is not founded on any difference in the nature of the variables; either variable may be treated as the independent variable.

20. Find the locus of the equation, $y-9x=0$.

21. Construct and discuss the equation, $y-5x^2=0$.

22. " " " " " $y-x^2+3=0$.

23. " " " " " $x^2+y^2=25$.

24. " " " " " $4x^2+9y^2=36$.

25. " " " " " $4x^2-9y^2=36$.

LECTURE NOTES.

III.

MECHANICS.

Kinematics.

MOTION:

The configuration of a system.
Change of place, or displacement.
Change of place with reference to time, or *Motion.*
A *Material Particle* defined.
Kinematics defined by Ampere.
Maxwell:

> "Any one who will try to imagine the state of mind conscious of knowing the absolute position of a point will ever after be content with our relative knowledge."

The Path, defined.
  Straight and *curved* paths.
Curvature, discussed.
  Curvature for a circle and other curves.
Speed and velocity discussed.
  Uniform Rectilinear Motion.
  Rectilinear, not uniform.
Acceleration.
  Accelerated motion discussed.
  Space and uniformly accelerated motion.

Free fall of bodies.

Derivation of the general formulas for the free fall of bodies, and their discussion.

Illustrations.

Projection upwards.

Composition of Motions.

Components and Resultant, defined.

The Triangle of Motions discussed.

Given two Motions and the Angle between them to find their resultant.

Projectile, Elevation, and Range, illustrated and discussed.

Motion on an Inclined Plane.

Illustrations and Derivation of formulas.

Descent down the Chord of a Vertical Circle.

Uniform Circular Motion.

Simple Harmonic Motion.

S. H. M. illustrated and discussed.

Stereopticon Projection of Circular Motion.

Acceleration and S. H. M.

Relations derived.

Velocity at any point, determined.

Composition of Circular Motions.

General Equations of S. H. M.

Relation of Kinematics to Kinetics.

Problems.

REFERENCES:

Carhart, Arts. 9–33.

Ames, Arts. 10–25.

Maxwell, Matter and Motion, Ch. II.

Thomson and Tait, Ch. I.

Nichols, Outlines, Chs. II., III., and IV.

Gage, Arts. 9–27.
Avery, Arts. 53–112.
C. and C., Arts. 40–61.

LABORATORY.

DYNAMICS.

Representation of force.

Read the following topics from the references furnished:

Dynamics.
Force.
Elements of Force.
Measurement of Force.
Momentum.
Laws of Motion.
Composition of Forces.
Resultant Motion.
Graphic representation of Forces.
Parallelogram of Forces.
Determination of the Force of a Resultant (a) mathematically, (b) graphically.
Composition of more than two forces.
Parallelopiped of Forces.
Resolution of Forces.

REFERENCES:

Nichols, Outlines, Arts. 10–16.
Wright, Arts. 42–52.
Nichols, Laboratory Manual, pp. 40–44.
Pickering, Arts, 23–25.

Exercise 5 (a). Balance two weights of 2 and 3 kgs. by a third, so as to form an angle of 20°.

Represent graphically and solve analytically.

(b) Balance three forces of 1 1.5 and 2 kgs. by a fourth so as to form angles of 120° with each other.

Represent graphically and solve analytically.

(c) Balance three forces of 2 kgs. each by a fourth, so that each will form an angle of 45° with any other.

Represent graphically and solve analytically.

MACHINES.

REFERENCES :

Nichols, Outlines, Arts. 59–69.
Nichols, Laboratory Manual, pp. 42–49.
Gage, Arts. 80–93.
Ames, Arts. 70–73.
Avery, Arts. 121–145.

See lecture Notes as follows:

Moments of a force.
Moments of the Resultant.
Parallel Forces.
Levers.
The Balance.
Center of Inertia.
Moment of Inertia.

Exercise 6 (a). A number of bars and a set of weights will be furnished you. Using these with the laboratory supports, make the following combinations:

1. Support the bar at its center and attach equal weights at its extremities. Does the bar remain in a horizontal position? Designating one weight by W, and the other by P,

the support by F, the distance from W to F, by W F, and the distance from P to F, by PF, find the product of P × PF and W × WF. Repeat several times, increasing P and W, and find product as above.

2. Change the point of support of the bar, and repeat several times as above, and compare products.

3. Change the point of support to one end of the bar. By means of the sliding pulley on the upper portion of the frame work, attach a weight to the other end of the bar so that it will act in opposition to gravity. Now, balance the bar by placing a weight at some intermediate point on it. Compare products as above.

4. Exchange points of attachment of the upward and downward weights. Compare as above.

5. Repeat case (1), using two more weights on each arm. Compare as above.

6. Construct a compound lever.

Instructions.—With the apparatus used above, construct a lever of the second class. At the upper end of the bracket construct a lever of the first class. Make the power of the lever of the second class the weight of the lever of the first class. Construct at the center of the bracket a lever of the second class. Make the power of the second lever constructed the weight of the third lever. Determine the statical law of such a construction. What are some of the practical applications of the compound lever?

Wheel and Axle (b) 1. Determine the relation between the weight attached to the wheel and that attached to the axle. Using the apparatus furnished you, make six different combinations.

2. Connect two wheels or pulleys of different diameters

by means of a belt or cord. Find the ratio of the number of revolutions of the two wheels during one revolution of the belt. Are the directions in which the two wheels rotate the same or opposite?

3. Given a pulley of a different diameter and number of revolutions. How may you determine the diameter of a second pulley that will give a required number of revolutions?

4. Upon the laboratory support attach pulleys so as to illustrate at least six different systems.

5. By means of a cylindrical piece of wood and a thick piece of paper, construct a device showing the relation between the inclined plane and the ~~pulley~~ screw. By a diagram show the methods.

(c) 1. Determine the coefficient of friction between two or more substances furnished you.

2. Verify at least three laws of friction.

THE BALANCE.

REFERENCES:

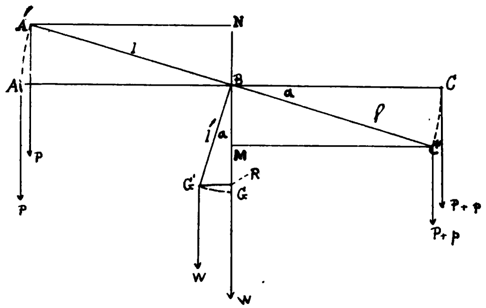
Stewart and Gee, Ch. III.
Carhart, Arts. 60-61.
Chute, pp. 23-32.
Nichols, Outlines, Ch. IX.
Austin and Thwing, pp. 18-34.
Pickering, pp. 46-50.
Kohlrausch, pp. 30-43.

GENERAL THEORY OF THE BALANCE.

REFERENCES:

Chute, pp. 23-32.
Austin and Thwing, pp. 18-34.
Pickering Phys. Manipulations, pp. 46-50.
S. and G., Ele. Prac. Physics., Chapter III.

By the sensibility of a balance we mean the angle through



which it will turn for a given difference between the weights in the pans. We shall now proceed to find the conditions which affect the sensibility of a balance. Let ABC be the

beam of the balance, its weight being W, and its arms each l units in length—the beam being fixed so as to be movable about the point B. Now, the center of gravity of the balance must be below this point, for if it were above B the equilibrium would be unstable, and the slightest addition of weight to either end of the beam would cause it to turn upside down; again, the centre of gravity must not be at B, for then the equilibrium would be indifferent, and the balance would rest equally well in any position. We shall, therefore, suppose the centre of gravity to be at G., at a distance l′ from B. Now, if weights P and P + p be suspended from A and C in such a manner as always to act vertically below their points of support, the balance will turn through a certain angle *a* and by the principle of the lever, the equation of equilibrium will be

$$(P+p)\ C'M = W \times G'R + P \times A'N$$

$$(P+p)\ l \cos. a = W\ l' \sin. a + P\ l \cos. a$$

$$pl \cos. a = W\ l' \sin. a, \qquad \text{or } \tan. a = \frac{pl}{W\ l'}$$

Thus the sensibility of the angle through which the balance turns for the given difference of weight p only depends on p, l, W, and l′, and we see from the formula that—

1. The longer the beam the greater the sensibility.
2. The lighter the beam the greater the sensibility.
3. The smaller the distance between the point of suspension of the balance and the centre of gravity, the greater the sensibility.

[From Stewart and Gee Elem. Prac. Phys.]

[Ex. 7, accidentally omitted]

Exercise 8. Determine the zero of the balance assigned you.

(a) Note. See reference above.

Determine the sensibility of the balance assigned you, using loads successfully of 0, 20, 30, 50, 100, and 200 grams. Tabulate the results and plot a curve for the same.

By "double weighing," determine the ratio of the lengths of the arms of the balance, i. e., determine if it is a false balance.

Manufacture a decigram weight. In testing your work, use the "method of vibrations." What are some of the advantages of this method?

DISTORTION.

(a) Torsion (b) Flexion.

REFERENCES:

Gage, Arts. 109-110.
Pickering, pp. 77-83.
Nichols, Outlines, Arts. 94-95.

Exercise 9. (a.) Using the apparatus furnished you, verify as nearly as possible the "Laws of Torsion."

Write the laws and construct their loci.

FLEXION.

(b) Using the apparatus furnished you, verify as nearly as possible the "Laws of Flexion."

Write the laws and construct their loci.

PENDULUMS.

REFERENCES:

Stewart & Gee, Arts. 150-153.
Stewart & Gee, Arts. 127-128.
Nichols, Laboratory Manual, pp. 67-69.
Pickering, Arts, 40-42,
Nichols, Outlines, Chaps. V. and VI.
Hopkins, pp. 46-55.
Loney, pp. 167-176.
Trowbridge, Ex. 52.

Exercise 10. (a) Suspend from the ceiling four balls of the same volume and mass; designate them as A B C and D. Suspend A and B by strings 99.3 cm. long, C by a string ¼ as long, D by a string 4 as long as A. Also suspend from the same height a piece of lath or similar piece of wood.

1. Cause A and B to vibrate by moving them equal distances from the vertical. What do you observe?

2. Cause them to vibrate by moving them unequal distances from the vertical. (In no case should the distance moved be over seven or eight degrees from the vertical.) What do you observe?

3. Cause A and C to vibrate by moving them the same angular distance from the vertical. What do you observe?

4. Give A and C different impulses by moving them to different angular distances. What do you observe?

5. Repeat as above with A and D. What do you observe?

6. Make a diagram illustrating the resolution of forces acting on the vibrating pendulum. Make diagrams of the cycloidal arc, and of the compensating pendulum.

(b) 1. Cause the lath and A to vibrate. Shorten A until it vibrates in the same time as the lath. Measure on the lath from the upper end a distance equal to the length of the string A. Bore a hole at this point. Place a small steel rod or wire in this hole, and cause the lath to vibrate on the rod or wire. How does the time compare with that of the previous vibrations?

Attach a string to the end of the lath and suspend the lath by it.

2. Strike the upper end of the lath. What motions do you observe with reference to different parts of the lath?

3. Strike the lower end of the lath. Observe as above.

4. Strike opposite the hole you have made. Observe as above.

Write the "Laws of the Pendulum," and construct the loci to illustrate the laws of the pendulum.

KATER'S PENDULUM.

(c) Determine the value of g by means of Kater's Pendulum. Nichols, Laboratory Manual, p. 69, Ex. E. 2.

(d) Torsion Pendulum. Determine the laws governing the Torsion Pendulum.

(e) Assuming the value of g as determined by means of Kater's Pendulum, find the moment of inertia of the iron ball furnished you.

Nichols, Laboratory Manual, p. 74, Exp. E, 4.

LECTURE NOTES.

IV.

DYNAMICS.

Statics *Kinetics*

of Solids.

Statics, defined.
Kinetics, defined.
Statics and Kinetics, how related.
Quantitative values, discussed.
Mass, Volume, Density.
- Mass, defined.
- Volume, defined.
- Density, defined.
- General formulas.

Momentum.
- General formula.

Force, quantitatively considered.
Impulse, defined.
The Dyne, defined.
Newton's Laws of Motion.
- Law I., discussed.
- Law II., "
- Law III., "

Inertia, illustrated.
Problems.

Work, defined.
- General formulas.
- The *Erg*, defined.
- Graphical Representation of Work.

Energy.
- Kinetic.
- Potential.

Energy distinguished from Force.
- General formulas.

General discussion of the Conservation and Transformation of energy.
- Available Energy.
- Entropy.

The Moment of a force, illustrated and discussed.
The Moment of the Resultant determined.
Parallel Forces, illustrated and discussed.
Couples, defined.
Levers, illustrated and general formulas derived.
Principle of the Lever by the Theory of work.
Three conditions of the Lever discussed.
Forces and the Inclined Plane.
The general formulas for the three conditions derived.
The Lever as related to the Balance.
The Determination of the zero.
The Sensibility.
Double Weighing.
The Centre of Inertia, and the Centre of Gravity.
The Moment of Inertia:
- With reference to Angular Acceleration.
- With reference to a Circle.
- About a Parallel Axis.

Problems.

The Ideal Simple Pendulum.

The Compound or Physical Pendulum.

The Reversibility of the Pendulum.

Kater's Pendulum.

Torsion Pendulum.

Cycloidal Pendulum.

Illustrations.

REFERENCES:

Carhart, Arts. 34-74.

Ames, Arts. 26-78.

Maxwell, Matter & Motion, Ch. III.

Nichols, Outlines, Arts. 35-95.

Gage, Arts. 28-100.

Avery, Arts. 53-145.

C. and C., Arts. 40-126.

LABORATORY.

Dynamics of Fluids. Density.

REFERENCES:

Nichols, Laboratory Manual, pp. 34-35.

Nichols, Laboratory Manual, pp. 79-93.

Nichols, Outlines, Arts, 106-114.

Stewart & Gee, Arts. 82-112.

Chute, Arts. 187-198.

Hall & Bergen, pp. 49-52.

Hopkins, p. 86.

Exercise 11. (a.) Determine the density of a regular solid, as a brass plate, rod, or tube.

Instructions: Measure its dimensions and compute its volume. Determine the ratio of its weight with that of an equal volume of distilled water.

(b.) 1. Determine the density of an irregular, insoluble solid, heavier than water, by means of the "overflow" method.

2. Determine as above by means of the "displacement" method.

3. Determine as above for a substance lighter than water.

(c.) Determine the problem given in (b) 1 and 2, by means of Nicholson's Hydrometer.

(d.) Determine by means of the Beaumé hydrometer the density of alcohol, milk, and a ten per cent solution of salt.

(e.) Determine the density of alcohol by means of Hare's method.

See Nichol's Laboratory Manual, p. 92, Exp. G. 9.

(f.) Determine by means of the Westphal Balance, the specific gravity of Alcohol, milk, and ten per cent solution of copper sulphate.

See Stewart & Gee, p. 140.

LECTURE NOTES.

V.

Dynamics of Fluids.

Liquids.

Liquids at Rest.
Pressure due to weight.
Friction in Fluids.
Pascal's Law.
Surface of Liquids.
Pressure and Depth.
Pressure on immersed surface.
Free Surfaces.
Archimedes' Principle.
Floating Bodies in Water.
Density.
Determination of Specific Gravity.
General Theory of Hydrometers.
Various forms of Hydrometers.
Capillarity and Methods of Illustration.
Law of Force Assumed.
Surface Tension.
Methods of Illustration.
Energy of Surface Tension.
Capillary Elevation and Depression.
Illustrations of Phenomena in General.

Gases.

Determination of the weight of Air.
Torricelli's Experiment.
Pressure of Air at different heights.
Barometers.
Floating bodies in air.
Pumps and siphons.
Theory of the siphon.
Pressure of gases measured.
Dalton's Law.
Boyle's Law.
Elasticity of a gas.
Air-Pumps.
Gas compression.
Marriotte's Flask.
Illustrations of Phenomena in general.

REFERENCES:

Carhart, Arts. 75-109.
Ames, Arts. 84-111.
Nichols, Outlines, Arts. 96-130.
Gage, Arts. 122-151.
Avery, Arts. 146-175.
C. and C., Arts. 127-175.

PROBLEMS:

LECTURE NOTES.

VI.

Sound.

Kinds of vibrations.
Recording periodic vibrations.
Sound, physiological and physical.
Definitions of sound.
Sources of sound.
Media of propagation.
Transmission of sound.
Sound waves:
  Characteristics of.
Determination of velocities.
Relations between velocity, wave-length, vibration-frequency, and period.
Simple harmonic motion applied to sound.
Wave motion as a curve of Sines.
Composition of simple harmonic motions in the same plane.
Interference and beats.
Graphic methods.
Reflection of a plane wave at a plane surface.
Echo.
Sound and music.
Musical intervals.
The Diatonic Scale or Gamut.

Laws of the Transverse vibrations of strings.
Overtones.
Partial tones and harmonics.
Vibrations of rods.
Tuning forks.
Vibrations of plates.
Resonance and organ pipes.
Overtones and fundamentals.
Vibration flames.
Kundt's experiments.
Quality of sound.
Musical pitch.
Doppler's principle.
Historical sketch of the development of music.

REFERENCES:

Carhart, Arts. 110-164.
Ames, Arts. 112-162.
Nichols, Outlines, Arts. 300-335.
Gage, Arts. 152-196.
Avery, Arts. 176-215.
C. and C., 395-471.
Tyndall, On Sound.
Everett, Vibratory Motion and Sound.
Blaserna, Sound and Music.

Problems.

LECTURE NOTES.

VII.

Heat.

Nature of Heat.
A form of energy.
Rumford's and Davy's experiments.
Measurement of temperature and its definition.
Expansion, linear and volumetric.
Thermometers, and thermometer scales.
Gas thermometers.
Liquid thermometers.
Metallic thermometers.
Zero points.
The zero of absolute temperature.
Irregular expansion of water.
The Law of Charles.
Quantity of heat.
Unit Quantity.
Fusion.
Influence of pressure on the melting point.
Latent heat of fusion.
Heat absorbed in solution.
Vaporization.
Ebullition.
Effect of pressure on boiling point.
Franklin's experiment.

Spheroidal state.
Sublimation.
Latent heat of vaporation.
Cold due to evaporation.
Methods of producing ice and cold artificially.
Distinction between a gas and a vapor.
Transmission of heat.
Thermodynamics.
Joule's experiment.
Rowland's experiment.
Kinetic theory of gases.
The steam engine.

REFERENCES:

Carhart, Vol. II, Arts. 1-104.
Ames, Arts, 163-213.
Nichols, Outlines, Arts. 131-190.
Gage, Arts. 197-272.
Avery, Arts. 216-253.
C. and C., Arts. 176-238.
Problems.
Stewart, An Elementary Treatise on Heat.
Maxwell, Theory of Heat.
Tyndall, Heat a Mode of Motion.
Day, R. E., Numerical Examples in Heat.

Problems.

LABORATORY.

Heat.

REFERENCES:

Chute, Arts. 199-283.
Trowbridge, Chap. X.
Nichols, Outlines, Arts. 131-210.
Hall & Bergen, pp. 168-243.
Balfour Stewart.
Day's Problems in Heat.
Matthews & Shearer, pp. 100-120.

Exercise 12 (a). Determine the coefficient of expansion of a metallic rod. Hall & Bergen, Arts. 146-147.

(b) 1. Determine the coefficient of expansion of a liquid. Chute, Art. 239.

2. With similar apparatus determine the variation for each half degree from 0° to 10° C. Plot a curve for the results obtained. Hall & Bergen, Art. 151.

(c) Determine the coefficient of expansion of air. Chute, Art. 241.

Calorimetry.

REFERENCES:

Nichols, Laboratory Manual, pp. 107-108.

Exercise 13. (a) Determine the water equivalent of a calorimeter. Nichols Laboratory Manual, pp. 109, 110; or Chute, Art. 271.

(b) Determine the "thermal capacity" of lead. Chute, Art. 272.

From the data obtained above determine the specific heat of lead. Nichols Laboratory Manual, p. 117, Exp. I., 3. Hall & Bergen, Art. 164.

(c) Determine the latent heat of water. Chute, Art. 275. Nichols, Outlines, Arts. 153-155.

(d) Determine the latent heat of steam. Chute, Art. 276. Nichols, Outlines, 156-157. Nichols, Laboratory Manual, p. 113, Exp. I, 1.

(e) Determine the heat of fusion of ice. Nichols Laboratory Manual, p. 117, Exp. I., 2.

Thermodynamics.

Exercise 14. (a) With the assistance of the engineer, take an indicator diagram from one of the engines of the Lewis Institute and determine its horse-power. Holmes, pp. 317-324.

LECTURE NOTES.

VIII.

Meteorology.

Meteorology defined.
Historical sketch of the growth of the science.
The modern contrasted with the earlier study.
Meterological instruments.
- The Barometer and Barograph.
- The Thermometer and Thermograph.
- The Anemometer and Anemograph.
- The Hygrometer.
- The Rain Gauge.

Meteorological phemomena.
- Dew, Fog, Mist and Cloud.
- Rain, Snow and Hail.
- Electrical Phenomena.
- Optical Phenomena.

Weather Forcasting.
The history and growth of the Signal Service.
How to make a weather map.

REFERENCES:

Buchan, Introduction to Meteorology.
Davis, Elementary Meteorology.
Scott, Elementary Meteorology.
Russell, Meteorology.
Greely, American Weather.
Weather Bureau Reports.
Blank Weather Maps.

LABORATORY.

Meteorology.

Exercise 15 (a). Read the barometer three times during each day during a period of two weeks and record. Read the thermometer immediately after reading the barometer, and record on same page with barometric readings. Plot curves for readings obtained.

(b) The weather.

1. Prepare a weather map from data given.

[NOTE.—Readings of the barometer, thermometer, wind., etc., will be furnished from the latest report of the Signal Service. Maps may be purchased of the Chief Signal Office, Washington, D. C.]

2. Prepare a second map from data given.
3. Prepare a third map from data given.
4. Prepare a fourth map from data given.

Insert into your record book one of the weather maps furnished you.

QUESTIONS.

1. Define meteorology.
2. Describe the principal instruments used in weather making.
3. How does modern meteorology differ from its earlier study?
4. Give briefly the history of the origin and growth of the Signal Service.
5. Describe the method by which weather forecasts are made.

LECTURE NOTES.

IX.

PHYSICS OF ETHER.

(*Ether Dynamics.*)

"RADIANT HEAT" AND LIGHT.

Ether dynamics.
Energy of ether strain.
Radiant energy in general.
The ether.
Effects of radiant energy.
Light defined.
Physiological definition.
Physical definition.
Nature and properties of light.
Rectilinear propagation.
Images produced by small apertures.
Theory of shadows.
Speed of light.
Reflection and the undulatory theory.
Images in plane mirrors.
Path of a ray to the eye.
Images of images.
Deviation produced by the rotation of a mirror.

Concave spherical mirror, theory of.
Principal focus.
Images in concave mirrors.
Caustics by reflection.
Convex spherical mirrors.
Refraction, laws of.
Construction of the refracted ray.
Critical angle.
Total reflection.
Refraction through a prism.
Construction for deviation.
Refraction at spherical surface.
The sign of the quantity "f."
Images due to lenses.
Optical center of a lens.
Spherical aberration and distortion of images.
Dispersion.
Chromatic aberration.
Spectra, kinds of.
Interference and diffraction.
Thin films.
Diffraction fringes with a narrow aperture.
Spectra by means of diffraction grating.
Wave lengths and vibration frequency.
Color.
Three primary color sensations.
Polarized light.
Double refraction.
Polarization by double refraction and reflection.
Nicol prisms.
Optical instruments.

REFERENCES:

Carhart, Arts, 165-235.
Ames, Arts. 297-377.
Nichols, Outlines, 336-390.
Gage, Arts. 273-392.
Avery, Arts. 254-323.
C. and C., Arts. 472-571.
Preston, The Theory of Light.
Tait, Light.
Aldis, Elementary Geometrical Optics.
Wright, Light.
Lommel, The Nature of Light.
Tyndall, On Light.
Lockyer, Spectrum Analysis.
Spottiswoode, Polarization of Light.
Vogel, The Chemistry of Light and Photography.

Problems.

LABORATORY.

"RADIANT HEAT" AND LIGHT.

REFERENCES:

Gage, Arts. 376-382.
" " 273-282.

Exercise 16. (a) In the laboratory will be furnished you a piece of apparatus called a "radiometer." Hold it in a vertical position a short distance from an iron ball that has been heated to about 200° C. What do you observe?

(b) Place the large concave reflectors furnished you at the opposite ends of your working table with the concave surfaces facing each other. Suspend a ball heated as in (a)

about 20 cm. in front of one reflector and the thermoscope at the same distance from the other reflector. Read the change in the thermoscope. Is heat reflected?

LIGHT.

REFERENCES:

Gage, Arts. 276-392.
Nichols, Outlines, pp. 370-413.
Nichols, Laboratory Manual, pp. 257-277.
Tait, Light.
Kohlrausch, pp. 148-209.
Lewis Wright, Light.
Dolbear, The Art of Projecting.

Exercise 17. (a) With the laboratory darkened, arrange several cardboard screens through which small openings have been made, so that when placed on the table the openings will be in a straight line. Place a source of light before the opening of one of the outside screens, and the eye before the other outside screen. Are you able to see the light of the flame? Displace first one screen and then another. Does it prevent the view of the flame?

(Note—Use electric and gas light attachments for the following exercises. You will find both at the corners of your working table.)

(b) In the darkened laboratory on one of the tables, place a cardboard screen through which is an opening over which a piece of tin-foil has been pasted. Place a lamp or gas jet on one side, about 30 cm. distant, and a cardboard screen about the same distance on the other side. Make a pin-hole through the tin-foil. What do you observe on the screen beyond the tin-foil? Increase the number of pin-

holes until you have completely removed the tin-foil, leaving one large opening. How has the appearance of the other screen changed? Explain the cause of images, and on what the distinctness of the image depends.

(c) In the apparatus used above, substitute for the screen with an opening another screen in which a circular opening 5 cm in diameter has been cut. Make the flame or source of light as bright and as small as possible. Adjust the screen with opening so that it will be midway between the light and the first screen. What is the ratio of the area of the opening and the illuminated part of the screen? Repeat several times, readjusting the apparatus, and take as your final result an average of the several trials.

Exercise 18. (a) Place upon the table about a meter apart two screens in vertical positions. Lay a mirror midway between them. Close to the outside of one of the mirrors place an electric lamp or gas flame and make a small opening in each screen on a line with the light. Look at the mirror through the opening in the screen on the opposite side of the light. Are you able to see the light from the flame or lamp? What is the law of reflection?

(b) In a darkened room cause a beam of light to fall obliquely upon a piece of unglazed paper. What is the result?

Place in a beam of light entering a darkened room a bottle containing smoke or water and slacked lime. What is the effect? Explain.

(c) 1. Place a bright object before a mirror. Compare carefully the apparent positions of the image and the object with reference to the mirror. Change your position and compare again. Applying what you have learned regard-

ing the reflection of light, endeavor to construct a diagram, explaining the cause of the image and its position. Give a rule that will apply in general to such constructions. Read Tait, Light pp. 63–68.

2. In the laboratory will be furnished you two long mirrors. Support them on the table, facing each other. Place a candle between them at one end. How many images are you able to see? Explain by diagram.

3. Place the two mirrors used above on the table, so as to form a right angle. Hold a light between them. How many images are formed? How does it affect the number of images?

4. Place a third mirror on the table at right angles to each of the others between the two used above. How many images are formed? Explain.

Exercise 19. (a)

Determine by experiment the principal focus of the concave mirror furnished you. Illustrate by diagram.

(b) Determine by experiment the conjugate foci of the mirrors furnished you. Illustrate by diagram. NOTE.—You will be required to discuss the formulas referred to in Tait.

(c) Make a diagram illustrating the method by which real images are formed by concave mirrors. Verify by experiment. Make diagrams, illustrating the size and position of the images as the distances of the objects are varied.

(d) Make diagrams illustrating the method by which virtual images are formed by concave mirrors. Verify by experiment.

(e) Make a diagram illustrating the method by which images are formed by convex mirrors. Verify by experiment. Review carefully the subject of light as treated thus far.

(f) With the sphereometer determine the radius of curvature of the concave mirror used above, and compare the results with those determined by experiment.

Exercise 20. (a) By means of the Rumford form of photometer determine the candle power of the electric lamps furnished you.

(b) By means of a Bunsen form of photometer determine the candle power of the electric lamps furnished you.

Give several practical uses of the photometer.

REFRACTION.

Exercise 21. (a) Reflect a beam of light obliquely upon the surface of water contained in a glass vessel. Make a diagram illustrating the effect of the water upon the beam of light.

Remove the water from the glass vessel used above and place a small regular object, such as a coin, on the bottom. Place your eye at some distance from the vessel and in such a position that you can see just the edge of the coin. Now fill the vessel with water and place your eye in the former position. Are you able to see more of the coin than before? Explain.

Look at a pencil placed back of a thick strip of plate glass, held obliquely to the line of sight. What is the effect? Diagram and explain.

Substitute for the glass in the above, a cell nearly filled with water and carbon disulphide. What do you observe? Explain.

(b) Determine the index of refraction of water with as much precision as possible, using the apparatus that will be furnished you.

(c) With the apparatus used above, determine the "critical angle" and the "angle of total reflection."

Learn the "Laws of Refraction."

(d) In the laboratory will be furnished you two glass prisms. Fix your eye upon some object not far distant. Now bring one of the prisms with one side parallel to the line of sight, between your eye and the object. What is the effect? Now bring the other prism in contact with the first, having its position reversed. What is the effect? Make a diagram showing the cause of the results obtained in each case.

(e) Make a diagram illustrating the different forms of lenses. Make a diagram illustrating the method by which we may conceive lenses to be "built up" from sections of prisms.

Learn the definitions of the following terms:

Center of curvature.
Principal axis.
Optical Center.
Principal focus.
Conjugate foci.

Exercise 22. Determine the focal distance of a convex lens by one of the four methods in Nichols, Laboratory Manual, pp. 261–264, Exs. X3.

Exercise 23. (a) Determine the magnifying power of a telescope. Nichols, Laboratory Manual, p. 264. Exp. X4.

(b) Determine the magnifying power of a microscope, Nichols, Laboratory Manual, p. 265, X5.

Exercise 24. (a) determine index of refraction of a prism by means of spectrometer.

Nichols, Laboratory Manual, p. 268, Exp. Y 1.

(b) In the laboratory will be furnished you spectroscopes, a Bunsen burner, several pieces of platinum wire fused in glass rods, and solutions of sodium, potassium, strontium, and lithium salts. Carefully examine the spectra of each of these salts. Make diagrams illustrating the direct vision spectroscope and spectrometer.

(c) Make diagrams illustrating, and explain fully, the "continuous," the "light line," and the "dark line" spectra.

Exercise 25. Determine the index of refraction of a plate of glass. Method, Kohlrausch, p. 157, Art. 39 A.

Exercise 26. Determine the distance between the lines of a "grating" by the diffraction of sodium light.

Method, Nichols, Laboratory Manual, p. 273, Exp. Y 3.

Exercise 27. Determine the wave-length of a ray of homogéneous light. Method, Kohlrausch, p. 173, Art. 42.

Exercise 28. Make diagrams showing the principles of construction used in the following instruments:

The Achromatic lens.

Photographic Camera.

Eye.

Simple Microscope.

Compound Microscope.

Opera Glass.

Reflecting Telescope.

Refracting Telescope.

Stereopticon.

LECTURE NOTES.

X.

Magnetism and Electricity.

Relation of magnetism to electricity.
Natural and artificial magnets.
Laws of Magnetic force.
Magnetic substances.
Magnetic induction.
Permanent and temporary magnets.
Magnetic fields.
Magnetic figures.
Magnetic shielding.
Consequent poles.
Strength of pole.
Unit pole.
Magnetic figures, theory of.
The earth a magnet.
Magnetic relation to currents.
Magnetic field about a "live" wire.
Magnetic field and a circular conductor.
Electro-magnetic unit of current.
Galvanometers:
Astatic, The D'Arsonval, The Potential.

Electrodynamics.
Electro-dynamometers.
Kelvin balance.
Electromagnetism.
Electro-magnets.
Permeability.
Hysteresis.
Laws of magnetic circuit.
Magneto-motive force.
Reluctance.
Motion in electro-magnetic systems.
Electro-magnetic induction.
Faraday's discovery.
Faraday's ring.
Self induction.
Growth of currents in induction.
Circuits.
Induction coils.
Discharges in vacua.
Roentgen rays.
The telephone.
Electrodynamic machinery.
Wattmeters.
Transformers.
Polyphase circuits.
Faraday's researches.
Maxwell's electromagnetic theory of light.
Hertz' researches.
Lenard's researches.
Roentgen's Work.
Summary.

REFERENCES:

Carhart, Vol. II., Arts. 105-377.
Ames, Arts. 214-296.
Nichols, Outlines, Arts. 191-299.
Gage, Arts. 393-558.
Avery, Arts. 324-447.
C. and C., Arts. 239-393.
Larden, Electricity.
Thompson, S. P., Elementary Lessons in Electricity and Magnetism.
Lodge, Modern Views of Electricity.
Hertz, Electric Waves.
Maycock, The Alternating Current Circuit.
Wright, The Induction Coil in Practical Work.

Problems.

LABORATORY.

MAGNETISM.

REFERENCES:

Nichols, Outlines, Arts. 244-255.
Nichols, Laboratory Manual, pp. 138-152.
Stewart and Gee, Vol. II., pp. 19-54.
Matthews and Shearer, pp. 160-168.

Exercise 29. (a) Suspend from one of the laboratory supports, by means of a stirrup the steel bar furnished you. Bring one end of a second bar near the suspended bar. What do you observe? Reverse the bar and repeat. What do you observe? Repeat, using the other end of the suspended bar. What are your observations?

(b) Provide yourself with several knitting needles. Holding one of them by the center, between the thumb and finger, and the center of one of the steel bars in the other hand, draw the pointed end of the needle firmly across the end of the bar, and then the other end of the needle across the other end of the bar. Repeat fifteen or twenty times. Prepare a second needle in like manner. Now repeat exercise 89(a), using the needles instead of the bars. What is the law of attraction and repulsion? What is the name given to the bars and needles above used? How are the ends designated? Name and describe different kinds of magnets?

(c) Break one of the needles used above and use one of the parts as in the above exercise. What is the effect?

(d) A knitting needle that has been magnetized to saturation will be furnished you. Break it into half a dozen parts. Arrange them on a board in the same order as when forming one needle, but with about three cm. between the pieces. Cover with a glass plate and clamp it to the board. Over the glass fasten a piece of blue print paper, sift iron filings over the paper, gently tapping the glass. When the filings have settled into position expose the apparatus to the sun for a few hours. Preserve the paper with your other records.

(e) Place a long bar magnet on the table and bring the needles, suspended in previous exercise, directly over the center of it. Slowly move, first toward one end, then toward the other. What do you observe? Explain.

(f) A compass mounted upon a scale will be furnished you; adjust it so that the needle will stand at right angles to the direction of the scale. Now place a bar magnet at the

extremity of the scale and gradually move it towards the needle. Note the change of distance for each change of 5° in deflection. Tabulate your results and plot a curve.

(g) Make diagrams of several different forms of steel magnets. What is an "armature"? What is meant by "variations of the magnetic needle"? How does the north magnetic pole differ in position from its corresponding geographical pole?

Exercise 30. Make a further and more detailed study of magnetic fields and lines of magnetic force, as follows:

(a) The field of a single "horseshoe" magnet.

(b) Two magnets with like poles near each other.

(c) Two magnets with unlike poles near each other.

(d) A bar-magnet placed in the field of a horseshoe magnet.

(e) A piece of soft iron in a magnetic field.

Complete the method in full as outlined in Nichols, Laboratory Manual, pp. 141-143, Exp. Q 1.

Exercise 31. Determine the permeability of bars of bismuth, tellurium, zinc, lead, and glass, by the method on p. 290, Nichols' Outlines.

ELECTRICITY.

I. Electrostatics.

REFERENCES:

Nichols, Outlines, Arts. 191-230.
Nichols, Laboratory Manual, pp. 122-137.
Stewart and Gee, Vol. II., Ch. I.
Matthews and Shearer, pp. 121-131.

Exercise 32. (a) In the laboratory will be furnished you an ebonite, a resinous (sealing wax), and a glass rod; also a piece of flannel and a piece of silk. Place a few small pieces of paper on the table before you. Rub the ebonite rod with the flannel and bring it near the pieces of paper. What do you observe? Repeat, using the other end of the rod. Are your observations the same? Repeat, using small pieces of silk thread. Repeat, using the piece of sealing wax with the paper and then with the thread. Repeat, using the glass rod with the pieces of paper and thread. Electrify (rub with flannel) the sealing wax, and suspend it in a stirrup. Electrify a second piece of sealing wax and bring it near the first. What is the effect? Repeat as above, using glass rods instead of sealing wax. Repeat, using ebonite instead of glass. Tabulate all the results obtained in the exercise.

(b) Attach a pith-ball to a piece of silk thread and suspend over a table. At some distance from this suspend a pith-ball by a linen thread. Using either the glass rod or

the sealing wax, electrify and bring near the first pith-ball. What is the effect? Electrify again and now allow the ball to touch the rod. What do you observe? Now press all parts of the ball against the hand and repeat. Are your observations same as before? Repeat, using ball suspended by moist linen thread. What are your observations? Explain the various conditions and changes in the balls and give the causes.

(c) In the laboratory will be furnished you a circular piece of tin plate, to which is attached a vulcanite handle. There will also be furnished you a circular piece of vulcanite, or rubber, a little larger than the tin plate. Slightly warm the vulcanite and electrify it with flannel or cat skin. Now place the tin plate on the vulcanite. Remove it and try the effect of a pith-ball suspended on silk. Observe effect. Again place it on the vulcanite which has been thoroughly rubbed with flannel. While in this position touch the tin plate with the hand. Now remove it and test its electrical condition by means of the pith-ball or the electroscope.

Exercise 33. (a) Verify the results obtained in Exercise 32 by means of the Gold Leaf Electroscope. For method see Nichols' Outlines, p. 215, Exp. 60.

(b) Determine the difference in conductivity of copper and glass by means of the Gold Leaf Electroscope. For method see Nichols' Outlines, p. 221, Exp. 61.

(c) Determine the polarity of an electrostatic generator by means of the Proof Plane and Gold Leaf Electroscope. For method, see Nichols' Outlines, p. 232, Exp. 63.

(d) Determine the properties of a condenser as a Leyden Jar. For method see Nichols' Outlines, pp. 246-250, Exps. 66 and 67.

II. ELECTRODYNAMICS.

I. Batteries.

REFERENCES:

Carhart, Primary Batteries.
Carhart and Patterson,
Nichols' Outlines, Chs. XXVI., XXIX., and XXXI.
Nichols' Laboratory Manual, Chs. VI. and VIII.
Gladstone and Tribe, The Chemistry of Secondary Batteries.
Gore, Electro-Metallurgy.
Gore, The Electrolytic Separator of Metals.
Plante, The Storage of Electrical Energy.

Exercise 34. (a) Fill a small vessel, as a beaker, or tumbler half full of water. Place also in the vessel a strip of zinc and a strip of copper, each about 2 x 10 cm., which you will find attached to a cover with binding posts. Do you observe any unusual phenomenon? Now add, slowly (stirring), about one-tenth as much sulphuric acid as you have water. Do you now observe anything new? Connect the binding posts together by means of the one ohm coil furnished you. Repeat your observations. Now exchange the zinc strip for one that has been amalgamated.

Repeat your observations.

Now ask an assistant to place in circuit for you a voltmeter. Close the circuit five times at intervals of one minute and note the readings of the voltmeter.

(b) Remove from the apparatus used above the voltmeter and substitute the one ohm coil. Place the wire above and then below the small compass furnished you and note the directions of the deflections. Placing the wire above the compass and reversing its connection with the plates, note the direction of deflection. Assuming that the greater chemical action takes place on the zinc plate, and that the direction of the current is from higher to lower potential, what is the direction of the current (1) in the cell (2) outside of the cell? If higher potential is denoted by positive and lower potential by negative, how may we express the same by mathematical signs? How may we designate the plates and how the electrodes?

Exercise 35. Methods of setting up different forms of cells.

(a) The Leclanche Cell. The following material will be furnished you; a glass jar, a porous cup containing the positive plate surrounded by manganese dioxide, a zinc pencil, 6 ounces of sal-ammoniac, and warm water. Fill the jar one-fourth full of water, dissolve the sal-ammoniac in it, then put the porous cup and the zinc pencil into the jar, also pour into the cup some of the sal-ammoniac solution. Allow the cell to stand fifteen minutes before using.

(b) The Daniell Cell. The following material will be furnished you: A glass jar, a porous cup, a perforated cup, a zinc prism, a sheet of copper, some zinc sulphate, some copper sulphate and water.

Make a five per cent solution of zinc sulphate and fill the porous cup half full of the solution; make a saturated solution of copper sulphate, and fill the glass jar half full of it; fill the perforated cup with copper sulphate crystals to insure satu-

ration, and set it into the jar containing the copper sulphate solution; put the zinc prism into the zinc sulphate solution in the porous cup, and set the cup into the glass jar with the perforated cup; put the strip of copper into the copper sulphate solution. Close the circuit a short time before using. Remove the porous cup containing the zinc when not in use.

(c) The Gravity Cell. The following material will be furnished you: A glass jar, a crowfoot zinc, copper plate, some zinc sulphate, some copper sulphate and water.

Make a five per cent solution and fill the jar one-third full of it; prepare a saturated solution of copper sulphate; hang the zinc plate to the edge of the glass jar; by means of a long necked funnel or rubber tubing introduce into the bottom of the jar a sufficient quantity of the copper sulphate solution to cause the zinc plate to be immersed in the zinc sulphate solution; introduce the copper sulphate into the bottom of the jar. Close the circuit through a resistance of five ohms for several hours before using. Close through a resistance when not in use.

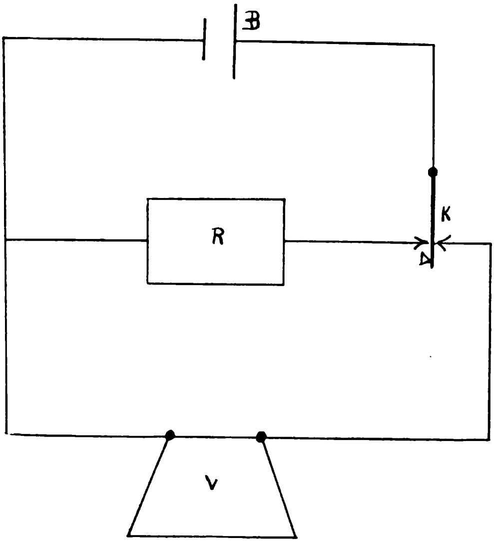
(d) Sodium Bichromate Cell. The following material will be furnished you; a glass jar, carbon and zinc plates, sodium bichromate, sulphuric acid and water.

Dissolve 20 grams of sodium bichromate in 200 cc. of boiling water. After the solution has been allowed to cool, slowly add 21 cc. sulphuric acid. After cooling again, place the zinc and copper plates into the solution. Remove the zinc when not in use.

Exercise 36. Polarization of cells.

(a) The simple cell. 1. Arrange the apparatus as shown in the diagram. B is the cell, R, a resistance of about 5 ohms, V the voltmeter, and K a double key. Do not close

the circuit through R until the first voltmeter reading has been taken. Then close through R and take ten voltmeter



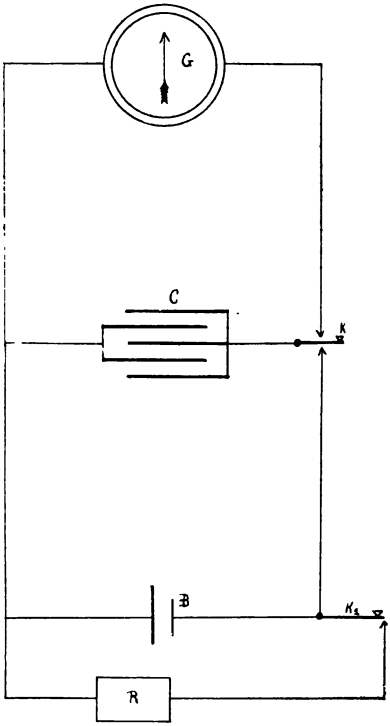
readings at intervals of fifteen seconds; follow with five readings at one minute, then five readings at intervals of two minutes.

2. Now open the circuit through R and repeat the readings as above. Tabulate results and plot curves, using volts as ordinates and minutes as abscissas.

(b) Repeat (a), substituting a Daniell cell for the simple cell. Plot curve as above.

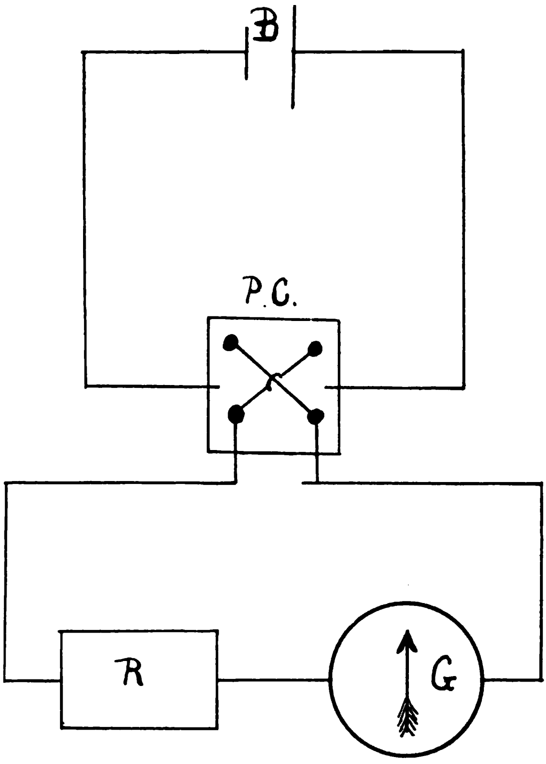
Exercise 37. Polarization of a simple cell by means of a condenser. Connect the apparatus as shown. G is a sensitive galvanometer; C, a condenser; K, a double key; K_1,

a single key; B, a simple cell; and R a resistance of five ohms. Pressing the key K, charges the condenser; releasing K discharges the condenser through the galvanometer.



In order to polarize the cell, the key K_1 must be closed, forming a circuit through R. The key K_1 must be opened when the readings are taken as in the other method. Take readings as in Exercise 36 and tabulate results.

Exercise 38. Measurements of E. M. F. (a) Connect up the apparatus as shown in the sketch. B is the battery; P. C. a Pohl's Commutator for reversing the current; R a



resistance; and G a galvanometer. Adjust the resistance so as to give a convenient deflection of the galvanometer and

take the reading; vary the known resistance and repeat. Determine the value of E from the following equation:

$$I = \frac{E}{R_1 + g}, \qquad I = \frac{E}{R_2 + g}.$$

(b) Check the results obtained above by substituting five different resistances, each time reversing the current through the galvanometer, taking as your final result the mean of the two deflections. Tabulate your results. Plot the curve, using the reciprocal of the current as ordinates and resistances as abscissas.

Exercise 39. Measurement of Internal Resistance. (a) Ohm's method. Connect the apparatus as in Exercise 34. Observe the galvanometer readings for eight or ten different resistances; take several readings with reversals for each resistance and use the mean as your final result for computation. From each suitable pair of observations compute the internal resistance from the following:

$$I = \frac{E}{R + g + r}$$

(b) Condenser method. Connect the apparatus as in Exercise 37. The operation consists in charging and discharging the condenser, first with the second key K_1, open and then with it closed, and noting the deflections d_1 and d_2.

$$\text{Then } r = R\,\frac{d_1 - d_2}{d_2}$$

See Carhart and Patterson, p. 100, Art. 55.

Exercise 40. Wheatstone's Bridge.

(a) The Slide Wire Bridge. Connect the apparatus as shown in Fig. 2. Substitute for "x" the coil furnished

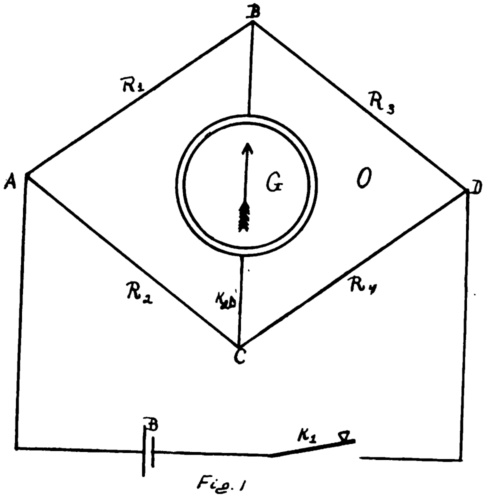


FIG. 1.

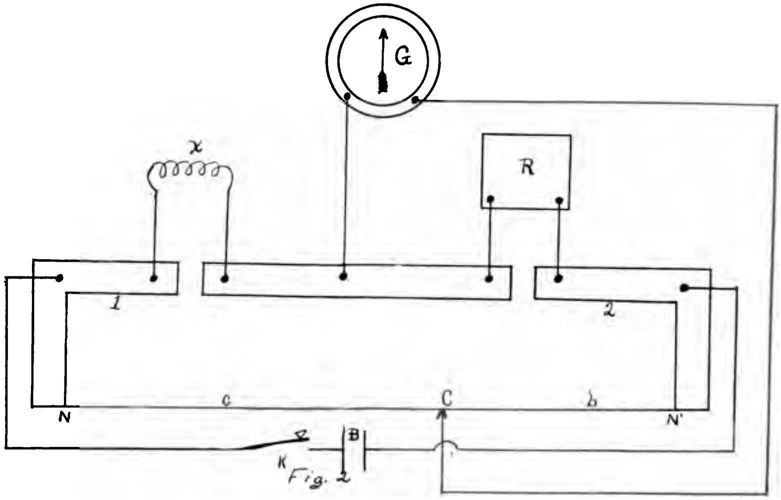
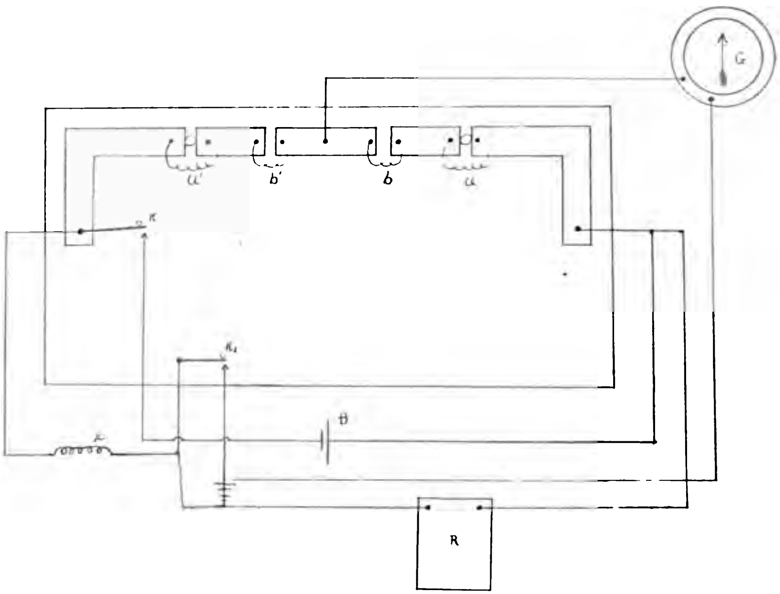


FIG. 2.

you. From the following relation in Fig. 1 base your calculation for the unknown resistance "x" in Fig. 2: $R_1 : R_2 :: R_3 : R_4$. Repeat, using at least five different coils. Tabulate results.



(b) Connect the apparatus as shown. Determine the resistance of the five incandescent lamps furnished. Tabulate results.

(c) Having given a galvanometer, connectors, a battery and resistances, determine the resistance of a given coil by Wheatstone's Bridge Method.

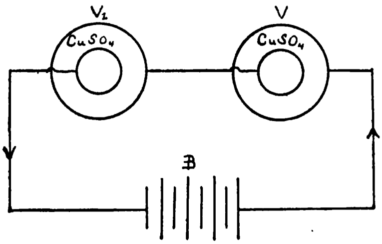
Exercise 41. Determination of the effect of joining cells in series and multiple by means of direct reading voltmeter and ammeter.

NOTE.—By *direct reading* voltmeters and ammeters are meant special forms of galvanometers through which the current must always be passed in the same direction, i. e. the + electrode of the battery must *always* be connected to the + binding post of the instrument.

(a) Mark six dry cells. 1. Determine the E. M. F. of each, by means of the voltmeter. Connect each cell separately in series with the ammeter and 5 ohm external resistance and note the current in each case. 2. Now connect the six cells in series with the voltmeter and note the E. M. F. Substitute for the voltmeter the ammeter and the 5 ohm resistance and note the reading. 3. Join all the cells in multiple and determine the E. M. F. by means of the voltmeter. Substitute for the voltmeter the ammeter and the 5 ohm resistance; note deflection as before. 4. Join in two series of three each; join these two in multiple. Repeat your observations as above. Tabulate all your results.

Exercise 42. Measurement of Current.

(a) The Copper Voltameter. Connect apparatus as shown.

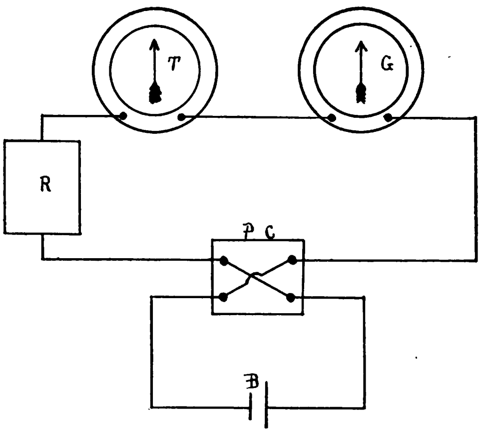


V and V_1, are the copper voltameters, and B a strong battery, or source of current.

1. Weigh all four coils as carefully as possible. Close the circuit from the transformer at a time carefully noted. Allow the current to flow for half an hour. 2. Remove the coils from the solution; dry them carefully by means of white filter paper and alcohol. Weigh the coils again and determine the change in weight of each. To determine the average strength of current that has passed through the voltameter, divide the difference in weight in grams by the number of seconds of time; again divide by .000328 to determine the number of amperes.

Exercise 43. (a) Calibration of any galvanometer by means of the tangent galvanometer.

In the diagram, T is the tangent galvanometer and G the galvanometer to be calibrated. P. C. is a Pohl's commuta-



tor, B is a battery, and R a variable resistance. Vary the resistance uniformly until ten readings have been obtained.

Tabulate results, and plot the curve. Make the calibration absolute by means of the ammeter.

For further instructions see Ayrton, p. 58, Art. 26.

Exercise 44. Suspend two strips of bright sheet lead in a dilute solution of sulphuric acid. Pass a current of ten amperes from the electrolytic generator through the cell thus formed for half an hour. Disconnect the terminals of the plates. Connect the terminals in series with an ohm resistance and an ammeter, the + electrode of the ammeter being joined to the anode.

Make ten readings at periods of 15 seconds, and plot the curve.

Read Gladstone and Tribe, The Chemistry of Secondary Batteries.

2. *Electromagnetism.*

REFERENCES:

Nichols, Outlines, Ch. XXVII.
S. P. Thompson, Lectures on the Electromagnet.
S. P. Thompson, the Electromagnet.
Matthews and Shearer, pp. 169–174.

Exercise 45. (a) Connect the coil of wire furnished you in series with the experimental current. Bring one end of the coil near one end of the pocket compass needle and note the effect. Repeat using the other end of the coil, recording each time your observations. Now remove the coil and place it at an angle of 45° with the needle and at such a distance that it does not affect the needle; introduce the bar of iron provided into the coil. Is the needle now deflected? Remove the iron. Is it now deflected?

(b) A compass mounted upon a scale will be furnished you; adjust it so that the needle will stand at right angles to the direction of the scale. Now place the coil previously used at the extremity of the scale, and gradually move it towards the needle. Note the change of distance for each change of 5° in deflection. Tabulate results and plot a curve.

3. Electromagnetic Induction.

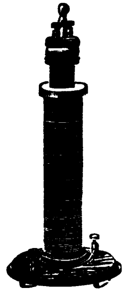
REFERENCES:

Nichols, Outlines, Ch. XXXIII.

Nichols, Laboratory Manual, Ch. X.

Matthews and Shearer, pp. 169-174.

Exercise 46. (a) Connect the outer coil illustrated in the figure with a sensitive galvanometer placed at some distance



from it, having first removed the inner coil and the iron core. 1. Bring a bar magnet in a vertical position slowly over the coil, then suddenly thrust it to the bottom, noting the action of the galvanometer. 2. Remove it suddenly, noting the galvanometer. 3. Slowly reverse the ends and repeat as in 1 and 2, noting the galvanometer.

(b) Substitute for the bar magnet, the coil previously removed, having first connected its terminals with the experimental circuit. 1. Repeat 1 and 2 of (a). 2. Reverse the connections at the terminals and repeat as in 1.

(c) Leaving the inner coil in position in the outer, repeat the observations of 1 and 2 in (a), using the iron rod.

(d) Repeat (b) leaving the iron rod inside the inner coil.

Exercise 47. The Telephone. The receiver and transmitter will be furnished you. Examine them carefully and make diagrams of each.

Exercise 48. The Induction Coil. A small separable induction coil will be furnished you. Separate the parts and make diagrams showing the connections. Now connect the parts as originally found.

4. Practical Problems in Electrodynamic Machinery.

REFERENCES:

S. P. Thompson, Dynamo Electric Machinery.
Slingo and Brooker, Electrical Engineering.
Fleming, Short Lectures to Electrical Artisans.
Crocker and Wheeler, Management of Dynamos and Motors.
Davis, Wiring Tables.
Matthews and Shearer, pp. 180.

Exercise 49. (a) Simple forms of dynamos and motors will be furnished you. Examine all parts and connections carefully and diagram accurately. Connect the motor to the experimental circuit, noting carefully the operation of different parts. Connect the motor by means of the belt furnished you to the dynamo. Connect the terminals of a voltmeter to the terminals of the dynamo and note the reading. Also connect the ammeter in series with a one ohm resistance coil to the terminals of the dynamo and note the reading. Measure the current and voltage furnished to the motor, and compute the efficiency of the system.

(b) Measure the resistance of the field coils and armature coils of both dynamo and motor by means of the Wheatstone's Bridge.

Exercise 50. (a) 1. Five incandescent lamps will be furnished you. Determine the resistance of each by one of

the methods previously used. 2. Connect each successively in the order previously tested with the experimental circuit and measure the "full of potential;" also measure the current flow. 3. Compute watts used in each lamp, and verify by means of the wattmeter. Allowing three watts as the energy required per candle, compute the candle power in each case. 4. Verify the candle power by means of the photometer in the dark room.

Exercise 51. (a) Determine the energy consumed in a given time in a 16 c. p. incandescent lamp. 1. A lamp prepared with water-proof socket and long terminals, mounted in a calorimeter, together with a thermometer, will be furnished you. Connect the lamp to the experimental circuit and determine as in previous experiments with calorimeters the energy absorbed in fifteen minutes. Compute the calories of heat produced by the lamp in one second.

(b) Allowing 20% loss, compute the horse power required to operate the lamps in the General Physics Laboratory.

Exercise 52. (a) Trace out all connections on the laboratory switch-board and make accurate drawings, illustrating the same.

(b) Make a drawing illustrating a method of wiring by which the lamps in the General Physics Laboratory may be connected and operated from the switch-board.

(c) Compute the cross section in circular mils of wire required above in order that the loss in pressure shall be one-half volt.

(d) Compute the H. P. necessary to drive a given dynamo from the following data: Electric power developed = 10,000 watts; gross efficiency of machine = 85 per cent.

(e) Compute the maximum output of current of a given dynamo from the following data: Required energy to drive machine at full capacity = 7,460 watts; normal pressure at terminals = 110 volts; net efficiency of machine = 82 per cent.

(f) Compute net efficiency of a motor from following data:

Current supplied = 10 amperes.
Pressure = 110 volts.
Power developed at pulley = 1.25 H. P.